Sustainable Energy Systems for Indoor Growing & Greenhouses

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Gas Major Accounts
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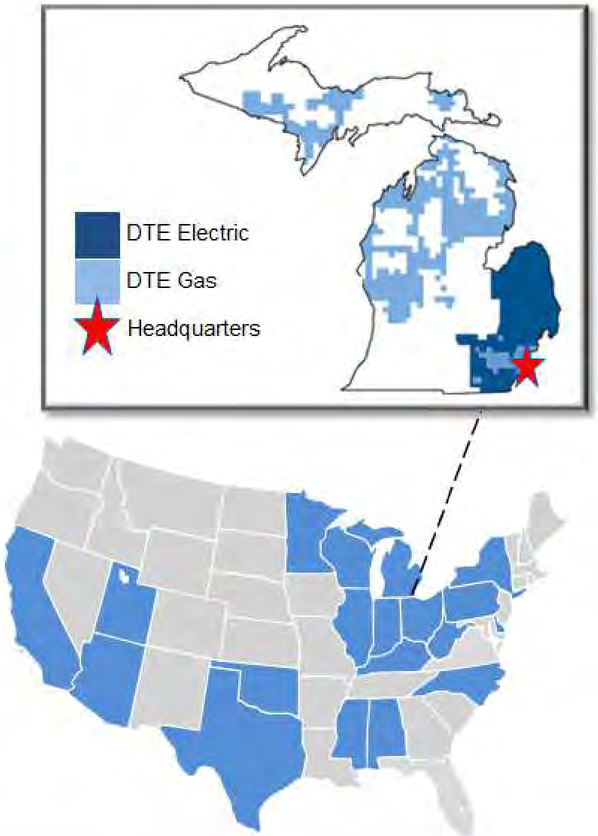
Outline

- Who is DTE Energy?
- What do plants need to grow and thrive?
- Elements of indoor, controlled grow environment
  – Envelope, Heating, Ventilation, Cooling and Humidity
- Delivery of Nutrients: Discussion of CO2 supplementation
- Lighting and Power options
- What is CHP?
- Greenhouse case studies
  – Two tomato greenhouses with multi-MW CHP systems
  – One indoor grow-room retrofit of a warehouse for cannabis
- Indoor grow-room energy balance and model
- Cost comparisons for a Michigan Class C 1,500 plant grow

DTE Energy is a Fortune 300 company with deep Michigan roots

DTE

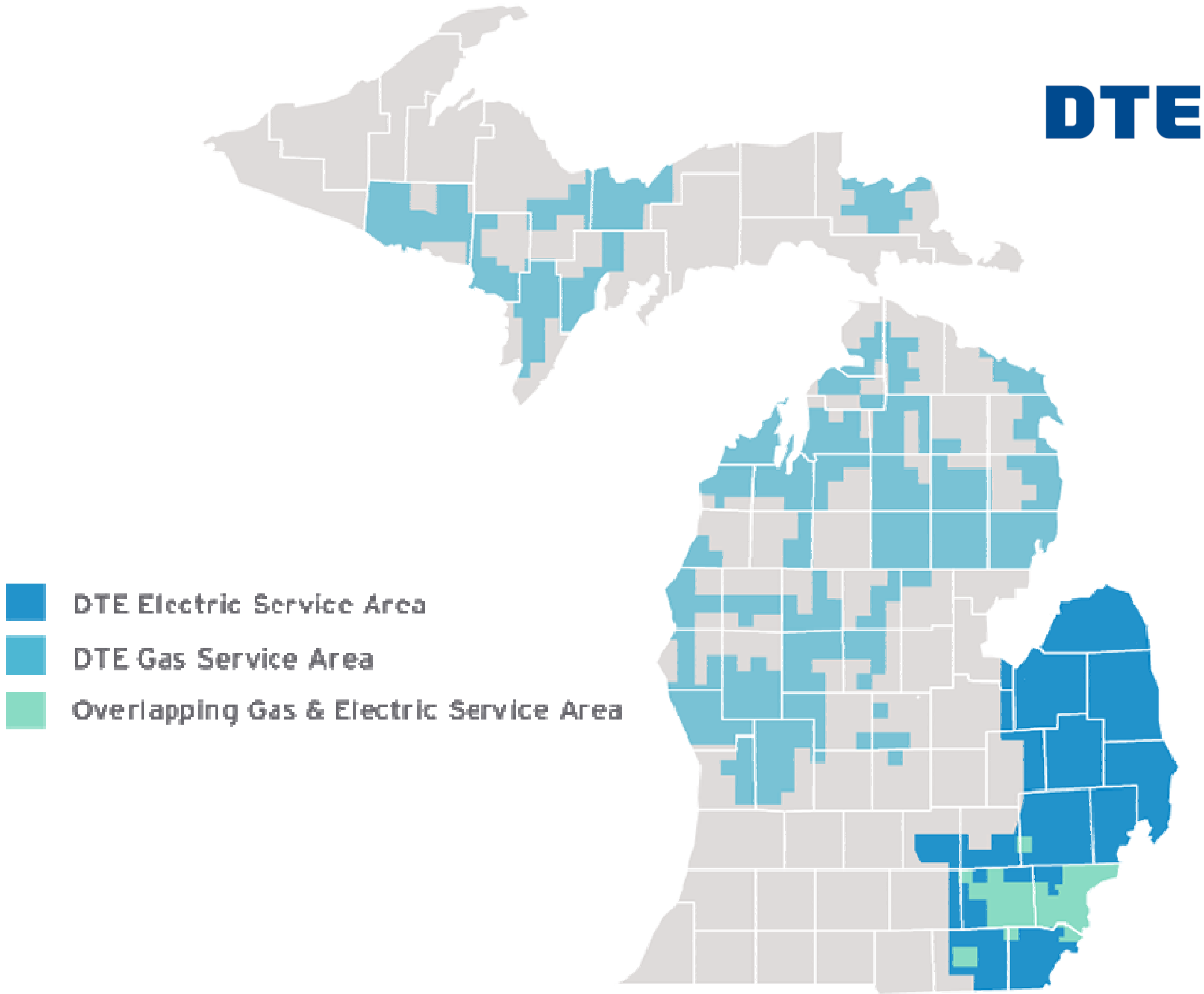


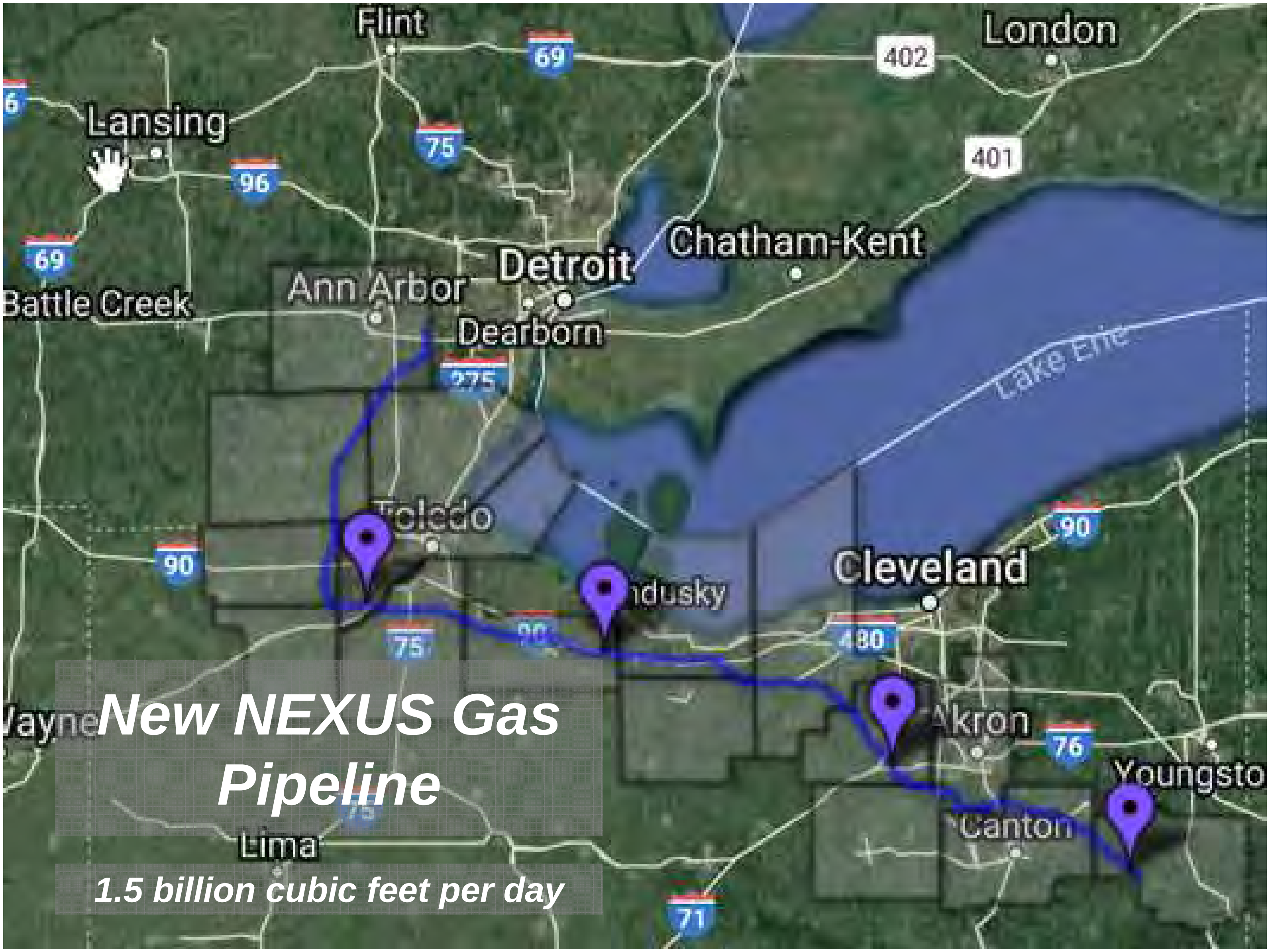
Our Business

- Market cap ~$18 billion
- Two fully regulated utilities serving Michigan
  - Founded in 1849, **DTE Gas**
  - Founded in 1886, **DTE Electric**
- Non-utility businesses operate in 19 states

Michigan Strength

- Top tier regulatory environment supports utility investment
- Constructive energy legislation supports transition to cleaner energy
- Strong state and local economy provides avenue for growth


DTE
DTE Electric Service Area
DTE Gas Service Area
Overlapping Gas & Electric Service Area


Flint
London
402
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Lansing
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Chatham-Kent
Detroit
Ann Arbor
Battle Creek
Dearborn
275
Lake Erie
Toledo
90
90
Cleveland
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480
Akron
76
Youngstown
Canton
Lima
71
New NEXUS Gas Pipeline
1.5 billion cubic feet per day


New 1,100MW
Gas Plant
New NEXUS Gas
Pipeline
1.5 billion cubic feet per day
Flint
London
Lansing
Detroit
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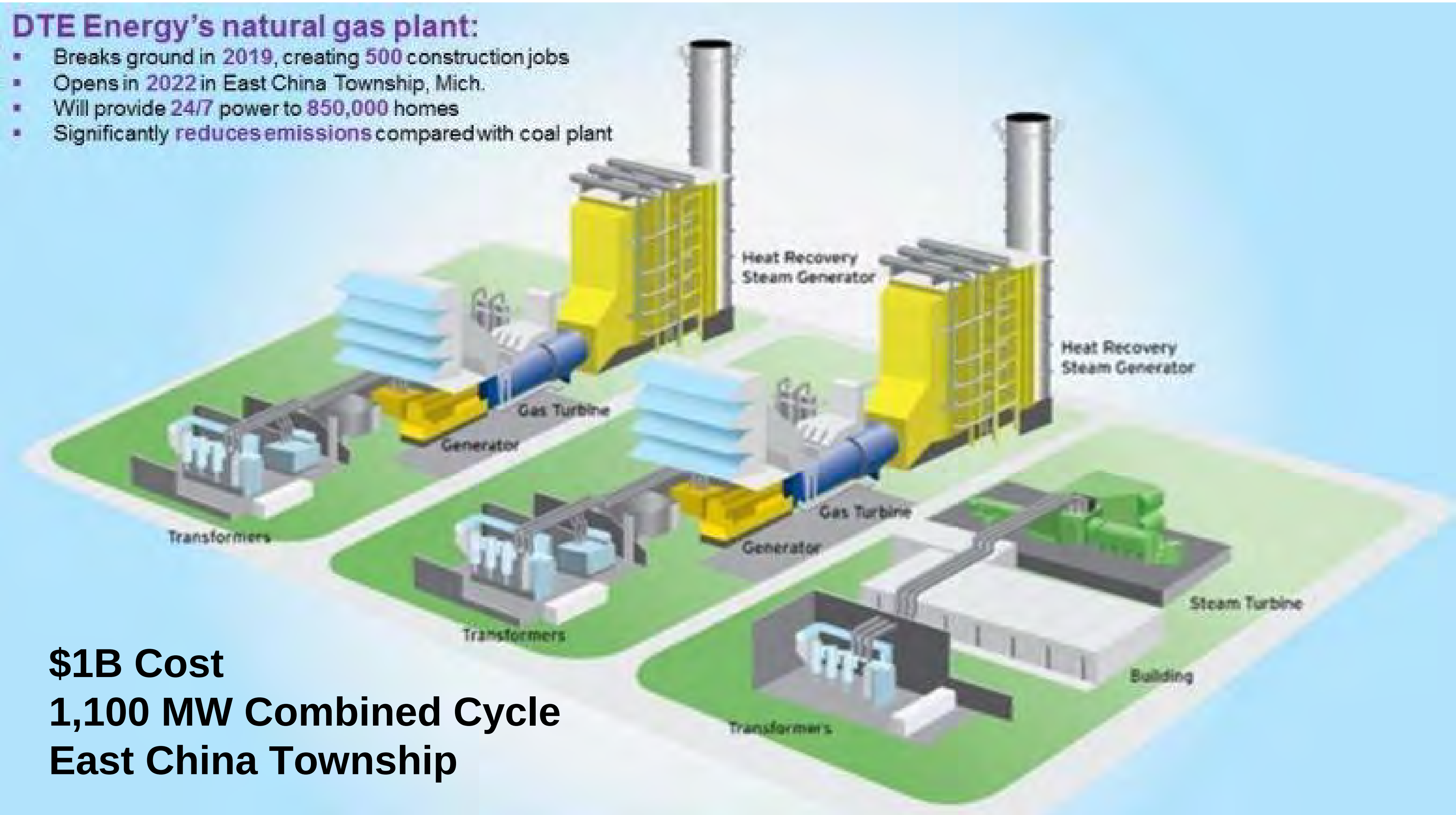
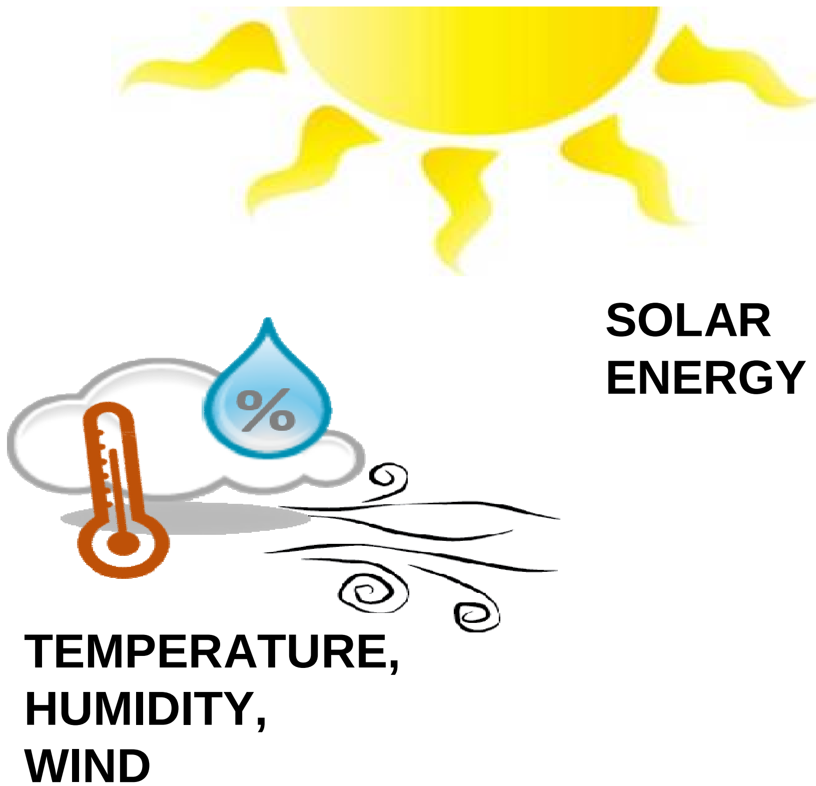
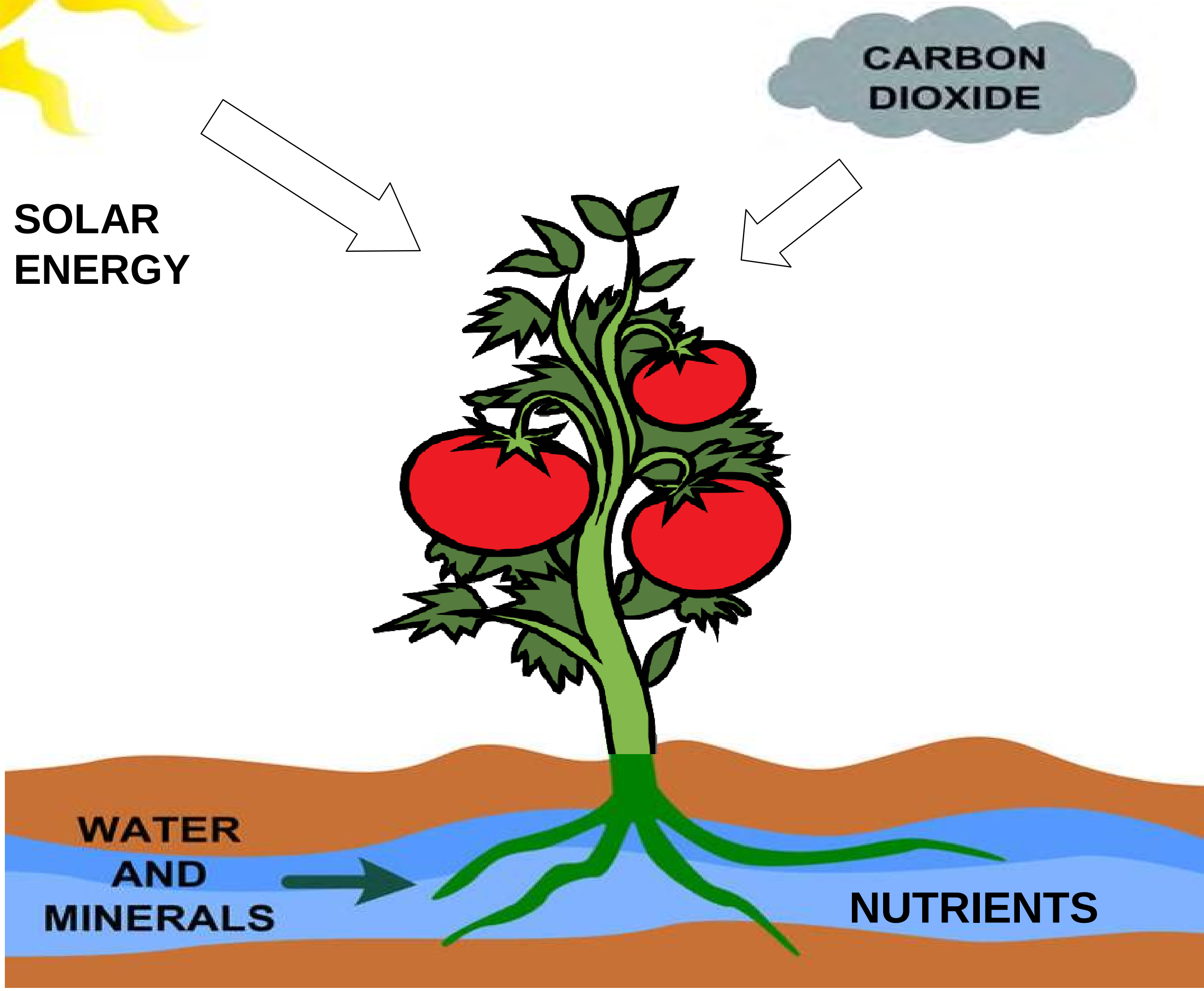
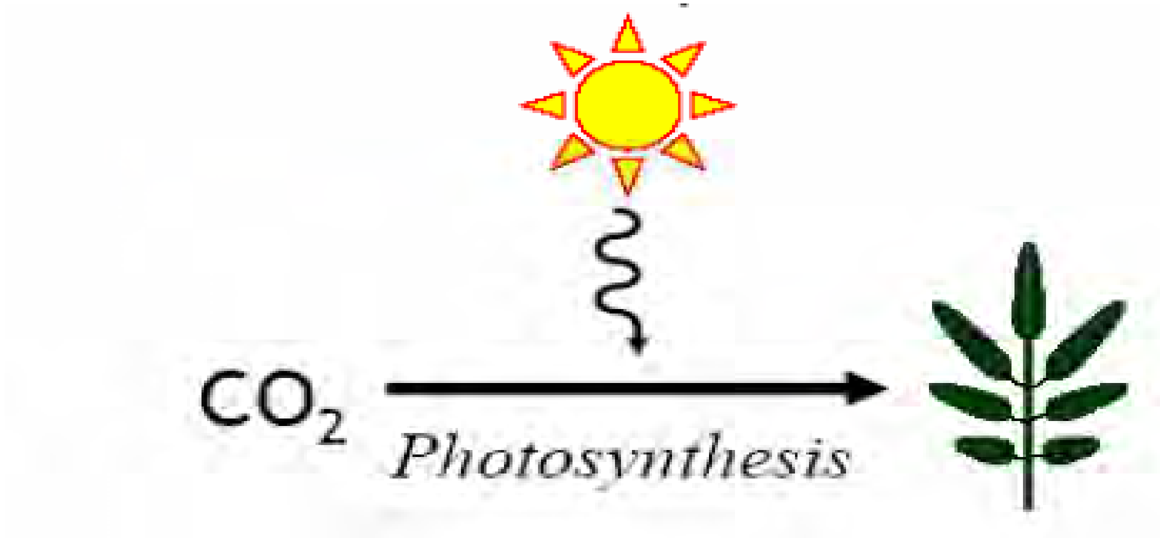

DTE Energy's natural gas plant:
Breaks ground in 2019, creating 500 construction jobs
Opens in 2022 in East China Township, Mich.
Will provide 24/7 power to 850,000 homes
Significantly reduces emissions compared with coal plant
Heat Recovery Steam Generator
Heat Recovery Steam Generator
Gas Turbine
Generator
Gas Turbine
Generator
Transformers
Transformers
Transformers
Steam Turbine
Building
$1B Cost
1,100 MW Combined Cycle
East China Township





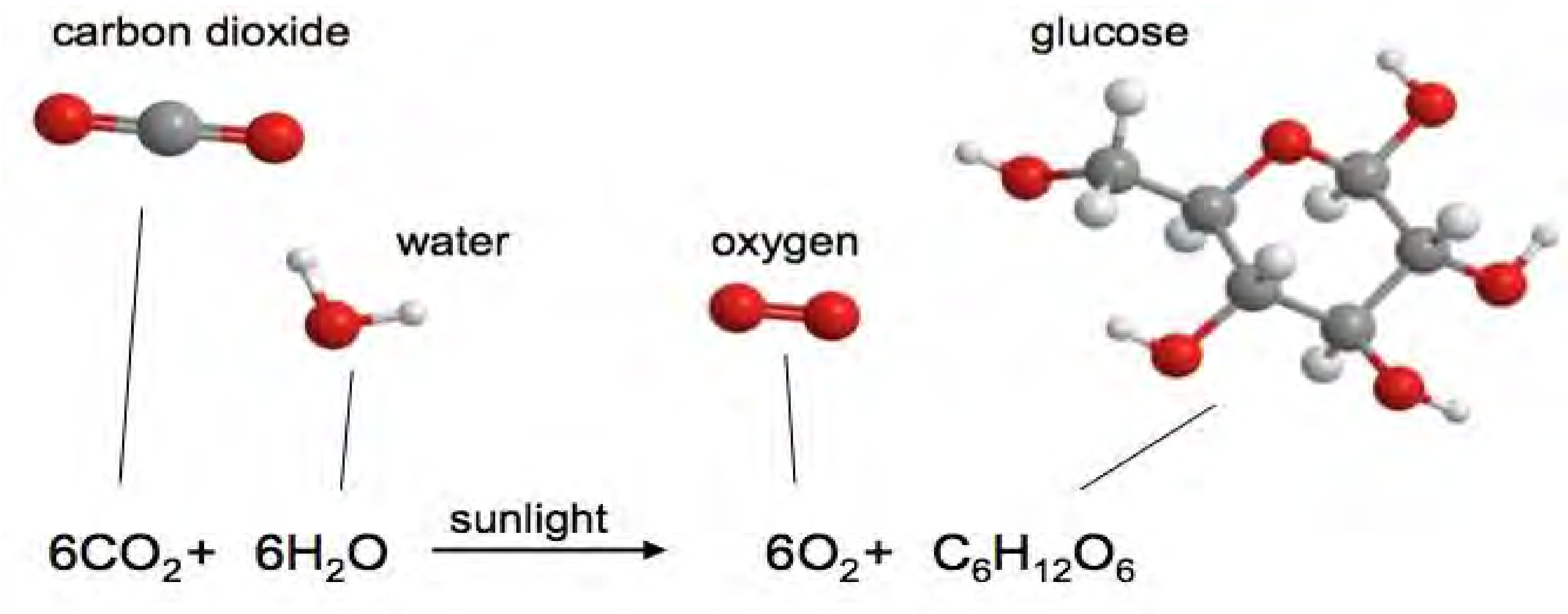
Elements for Healthy Plant Growth

Photosynthesis – chemical reaction



$6CO_2 + 6H_2O$ + solar energy $\Rightarrow$ $6O_2$ + glucose

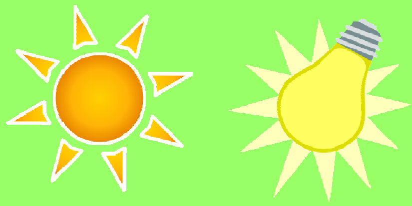
Glucose = $C_6 H_{12}O_6$



Nearly all life on the planet is supported by this reaction

Controlled Environment Agriculture

- Provide Light Energy
  - Solar or Artificial



- Macro Nutrients
  - CO_2 and H_2O
- Micro Nutrients: N, P, K, other Minerals
  - Soil or Hydroponics
- Suitable Environment
  - Temperature, Humidity, Wind ***(ventilation)***

Elements of a Greenhouse

- Building envelope
  - Weatherization / air infiltration
  - heat insulation
  - light transmittance
- Lighting
- Heating
- Ventilation
- Cooling
- Humidity control
- Delivery of nutrients
  - CO_2, water, fertilizer (N,P,K and minerals)
- Supply of energy: electric utility, natural gas, renewables, CHP

The Structure or Envelope

- **Reduce Air Leaks**
  - Weather-strip doors, vents and fan openings
  - Service louvers frequently to close tightly
  - Repair broken glass or holes in the plastic
  - Seal and weatherize foundation
- **Double Coverings**
  - Cover "inside" sidewalls and end walls inside with poly or bubble wrap
  - Install double wall polycarbonate panels to get insulation effect and reduce recovering labor.
  - Use poly with an infrared inhibitor on the inner layer for 15% savings
  - Use single or double layer of plastic over older glasshouses to reduce infiltration and heat loss
- **Energy Conserving Curtain**
  - Install a thermal curtain for 20%-50% savings. An energy curtain can significantly reduce nighttime heat loss from a greenhouse. Payback within 1 to 2 years.
- **Foundation and Sidewall Insulation**
  - 1-2" extruded polystyrene board to 18-24" below ground to reduce heat loss. This can increase the soil temperature near the sidewall as much as 10 degrees during the winter.
  - 1-2" board insulation on kneewall or sidewall up to bench height.
- **Site Location**
  - Locate greenhouses in sheltered, reduced wind areas (but not shaded)
  - Windbreaks on the north and NW exposures with rows of conifer trees or plastic snow fencing.
- **Space Utilization**
  - Optimize space utilization: movable benches, multi-level racks for low light crops, try addition of hanging baskets, and roll-out bench system can double growing space, where top level plants are moved outside during the day.

Automated Night Thermal Curtains

Photo: John Bartok, Jr., University of Connecticut

Heating Options

- Consider Thermal Storage
- Direct fired unit heaters (CO_2 + heat)
- Indirect fired unit heaters
  - High efficiency condensing unit heaters (90%+)
- Natural gas boiler, natural gas
  - Radiant piping distribution
  - Radiant floor distribution
- **Combined Heat & Power (CHP), natural gas**
- Engine driven heat pumps, natural gas
- Ground source heat pumps, electric
- Renewable options
  - Solar thermal or Biomass (wood chips)

Ventilation Options

- None: sealed environment (cannabis grow room)
- Automated roof vents
- Sidewall electric fans
- Need to coordinate and control interactions with CO_2 supplementation

Cooling Options

- Natural ventilation only
- Side wall evaporative cooling
- Shading
  - Shade curtains or Exterior spay on white-wash
- Ground source heat pumps, electric
- **Natural gas engine driven heat pumps**
- **Natural gas absorption cycle chillers and heat pumps**
- **Natural gas engine driven chillers (TecoChill)**
- Grow rooms best utilize natural gas heat pumps or chillers due to predominant cooling and dehumidification loads.

Gas Cooling & Heat Pumps: (tons cooling)

- Yanmar **gas engine** driven heat pump: (13, 16, 20, 24)
- Sierra / Aisin **gas engine** heat pump: (8, 15)
- Tecochill **gas engine** air-cooled water chiller: (25)
- Tecochill **gas engine** air-cooled water chiller: (50, 65)
- Tecochill **gas engine** water cooled chiller: (150 to 400)

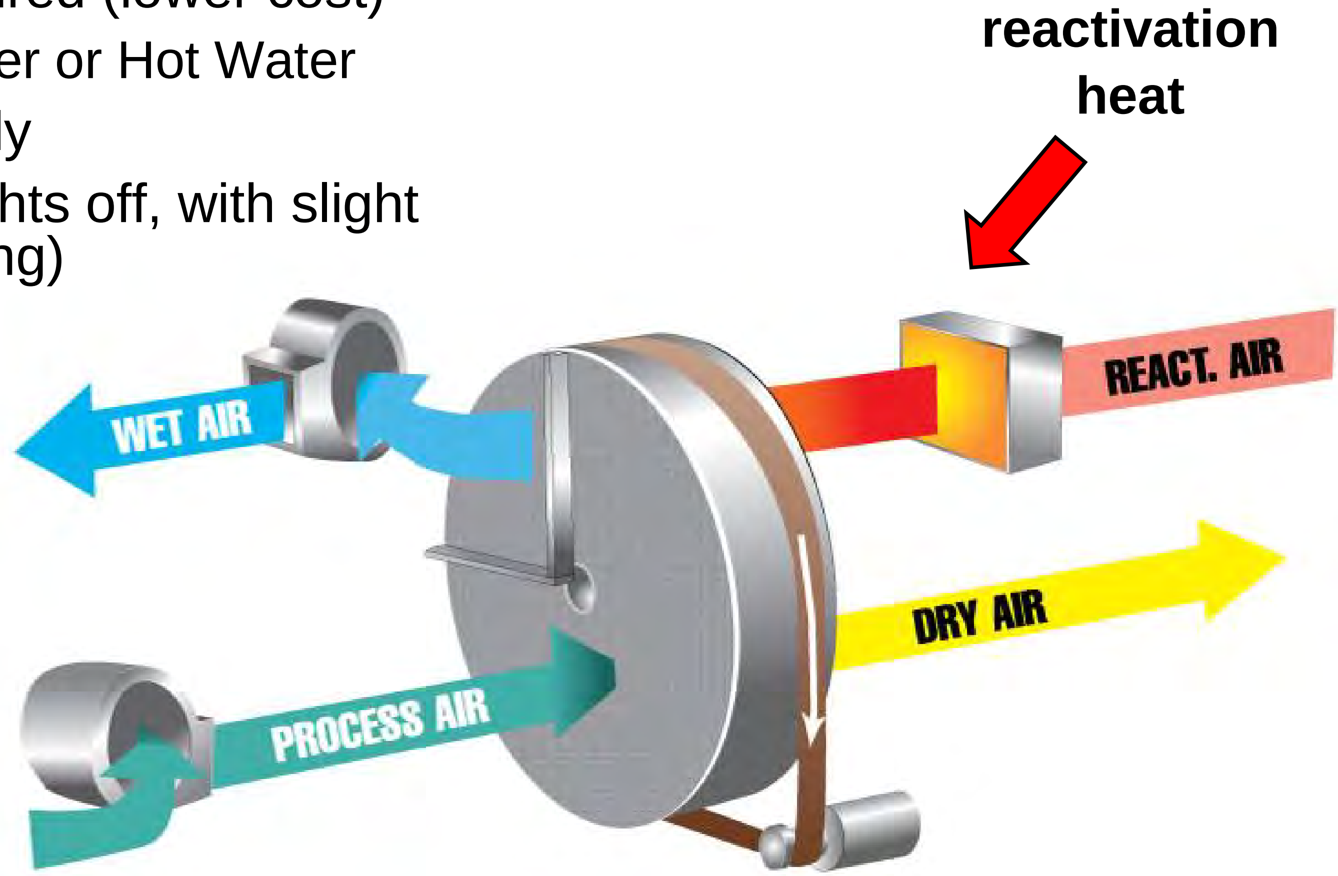
- Robur gas fired, **absorption** heat pump: (5)
- Yazaki gas fired or HW driven, **absorption** chiller: (5 to 100)
- York/Johnson Controls/Hitachi **absorption** chillers: (30 to 4000)
- Trane HW driven **absorption** chillers: (112 to 465)
- Thermax (India) HW driven **absorption** chillers: (20 to 1150)
- Broad (China) HW driven **absorption** chillers: (66 to 3307)

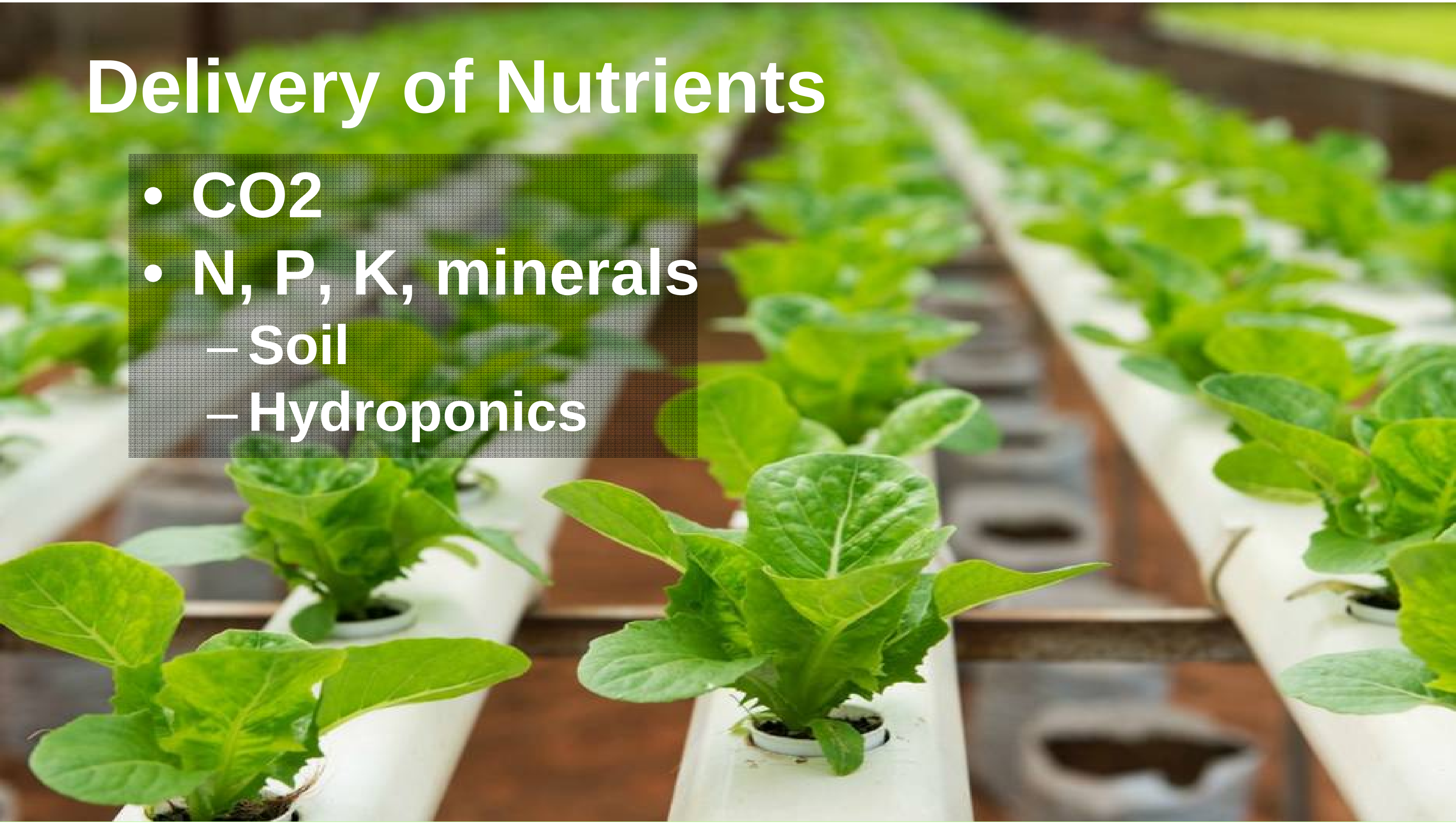
Humidity Control

- Ventilation with outdoor air
- Active refrigeration based or chilled water dehumidification
- Desiccant dehumidification with thermal reactivation (best practice for grow-rooms)

Grow room desiccant dehumidification

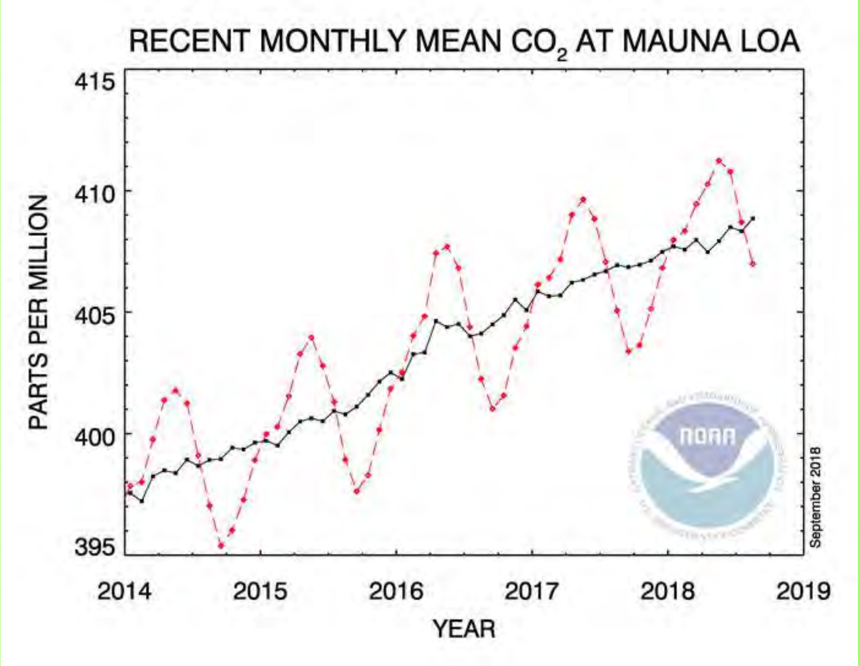
- Electric or natural gas fired (lower cost)
  - Direct fired gas burner or Hot Water
- Electricity to run fan only
- Can dehumidify with lights off, with slight heating effect (no cooling)
- Best used with waste heat from ***CHP***, or engine driven cooling systems, (essentially free dehumidification)



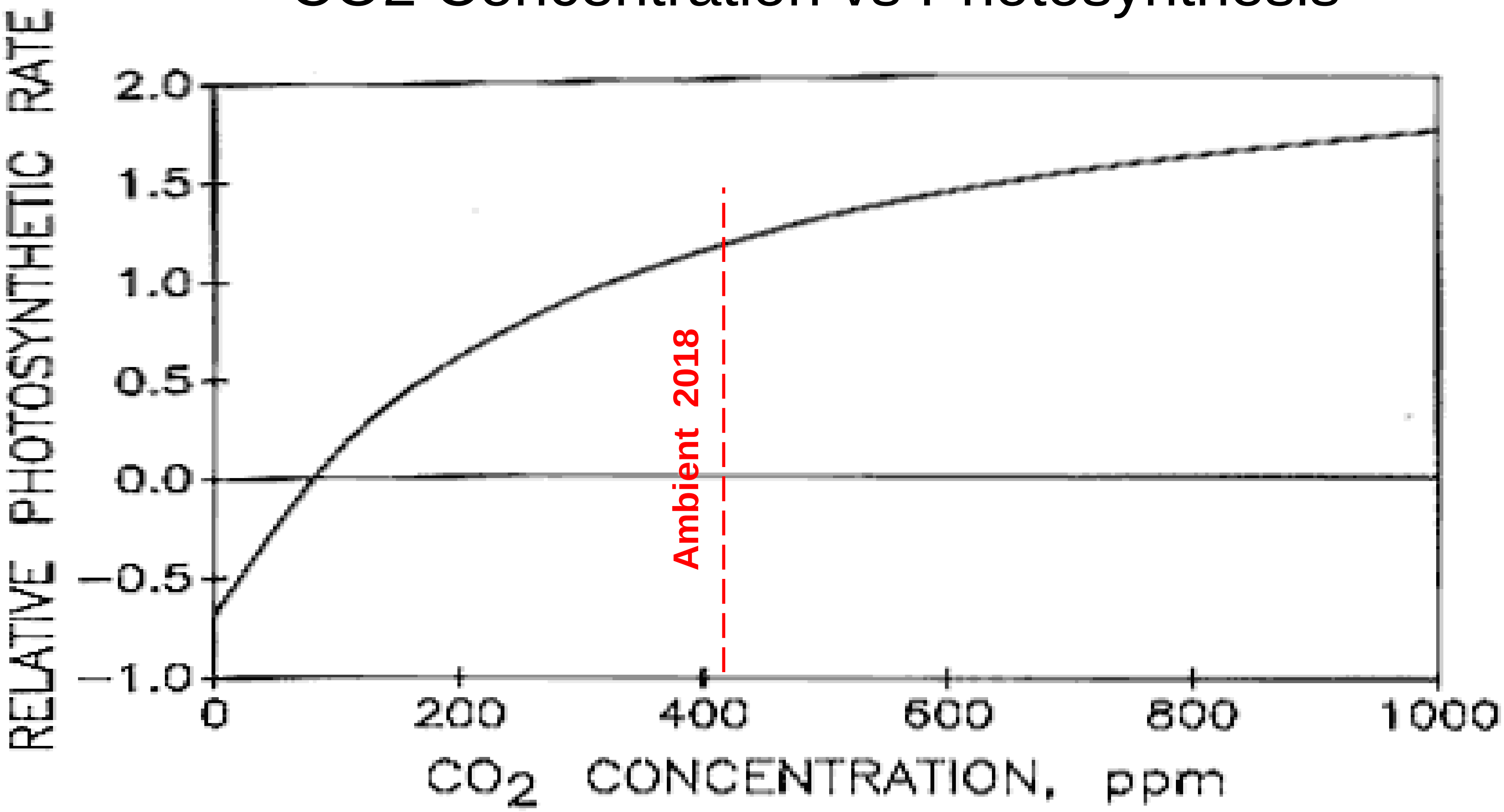

Delivery of Nutrients
• CO2
• N, P, K, minerals
– Soil
– Hydroponics

CO2 Supplementation

- Ambient CO2 ~410 ppm (April 2018)
- During daylight hours CO2 may be rapidly depleted during crop production
- Depletion may be exacerbated during winter production when there is less ventilation
- Yields can increase ~33% if CO2 doubles



CO2 Concentration vs Photosynthesis

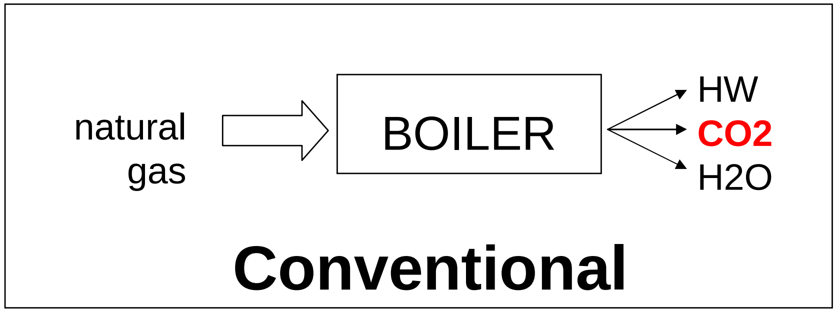


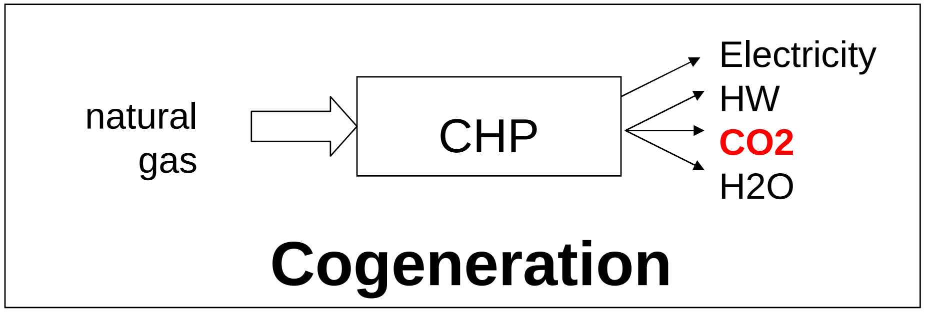
CO_2 Concentration Levels

- 1,000 ppm or more have shown to increase tomato yields economically
- However, you must adjust based on plant maturity and environmental conditions
  - Bright, sunny weather 1000 ppm
  - Cloudy weather 750 ppm
  - Young plants 700 ppm
  - During moderate ventilation 350-400 ppm
  - Less needed as temperature and ventilation rates increase

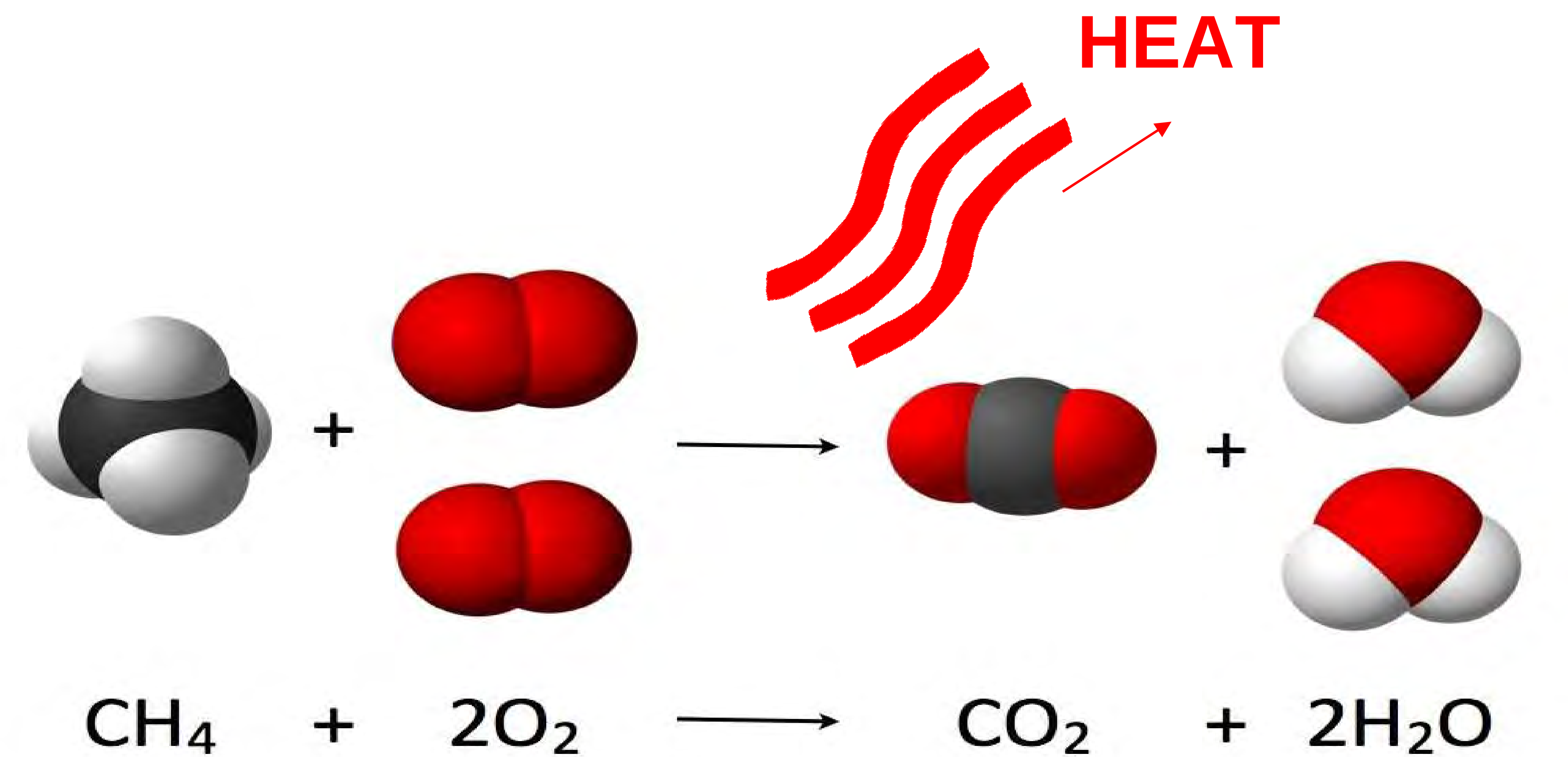
CO2 Supplementation Sources

- Liquid CO_2 ***(relatively inexpensive)***
- Combustion of natural gas or propane
  - Direct fire burners
  - ‘Conventional” Boiler exhaust
  - CHP engine or turbine exhaust





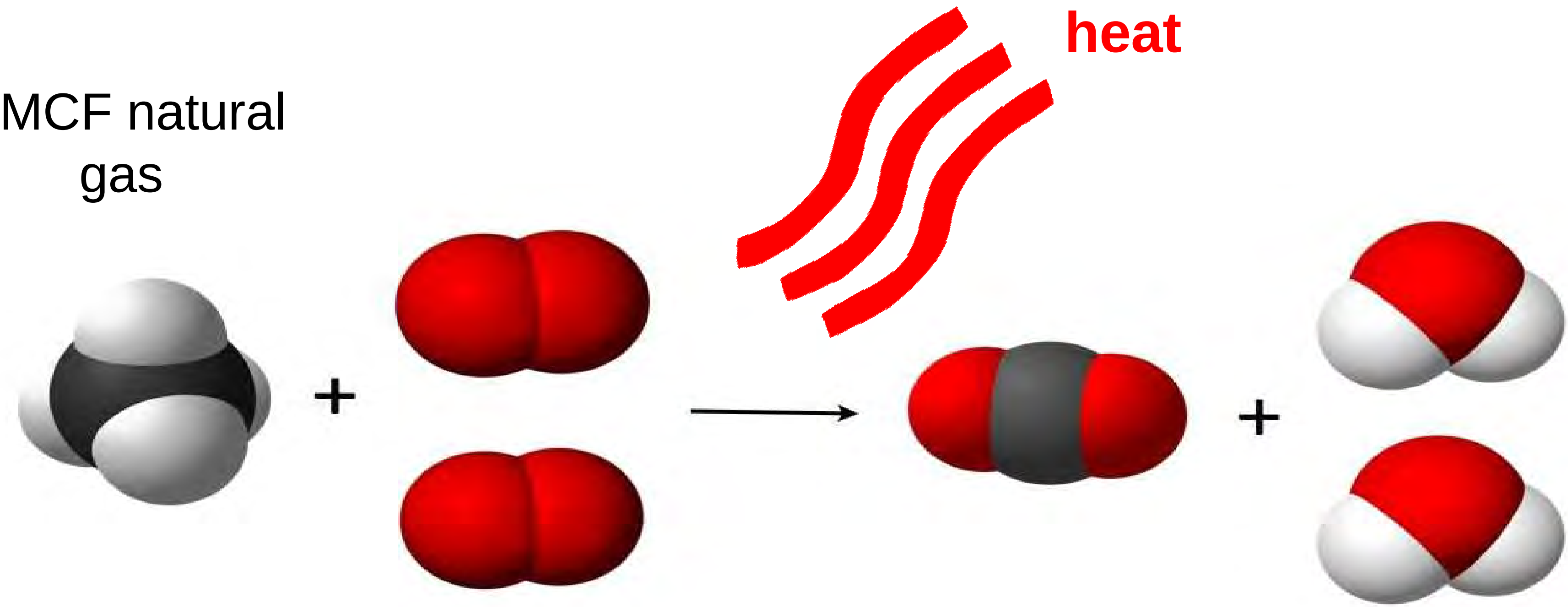
Natural Gas Combustion



Natural Gas Combustion

1 MCF natural gas

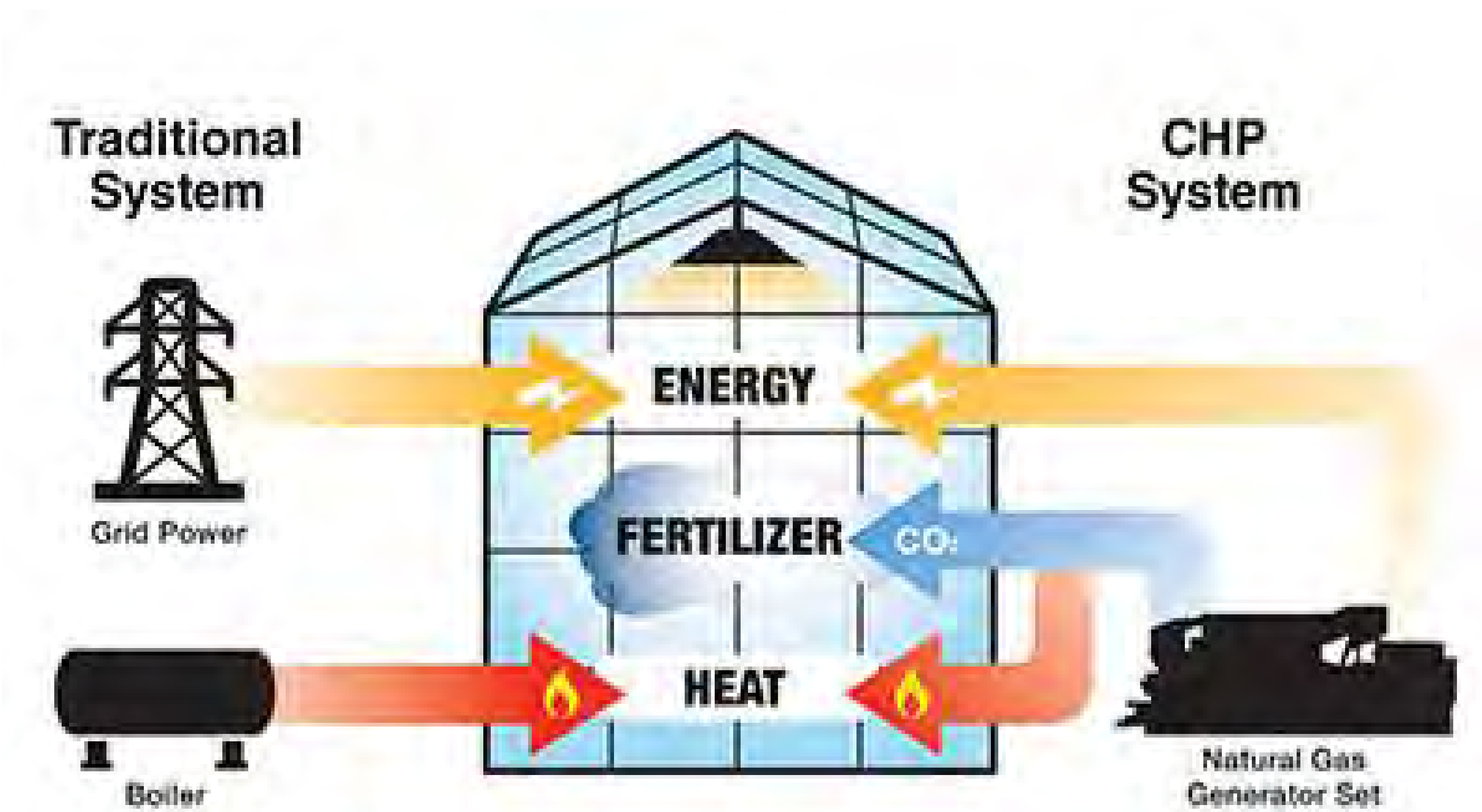
1 MMBTU heat



11.4 gallons water

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

CH_4	$2O_2$	CO_2	$2H_2O$
53 lb	159.5 lb	117 lb	95.7 lb


Traditional System
CHP System
Grid Power
ENERGY
FERTILIZER
CO_2
HEAT
Boiler
Natural Gas Generator Set

Cost of Natural Gas Derived CO_2

Approximately 1 Lb. of CO_2 per hour per 1,000 sq. ft. yields 1,000 ppm's of CO_2

Source: http://www.johnsongas.com/industrial/CO2Gen.asp

Natural Gas CO_2 Generation

117 lb per MMBTU

MMBTU	**$ / lb CO_2**
$4.00	$0.034
$5.00	$0.043
$6.00	$0.051
$7.00	$0.060
$8.00	$0.068

Supply of Electricity

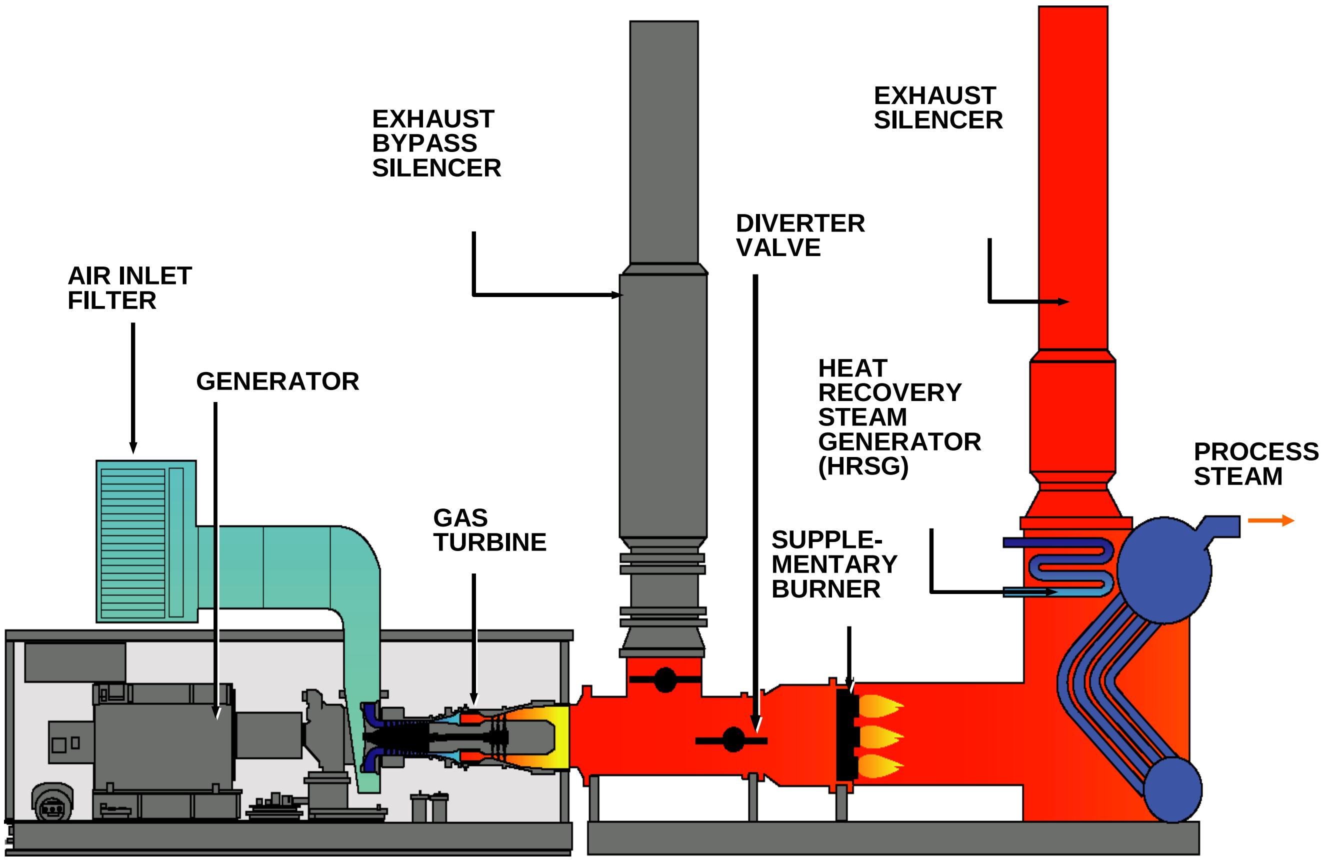
- Utility company
- Renewables
  - Solar PV
  - Wind turbines
- Combined Heat and Power
  - Special case for greenhouse application
  - It is a heating source (boiler)
  - It is a distributed generation source
  - It is the best “Energy Efficiency” technology
  - It is also a source of CO2 and H2O

Combined Heat and Power

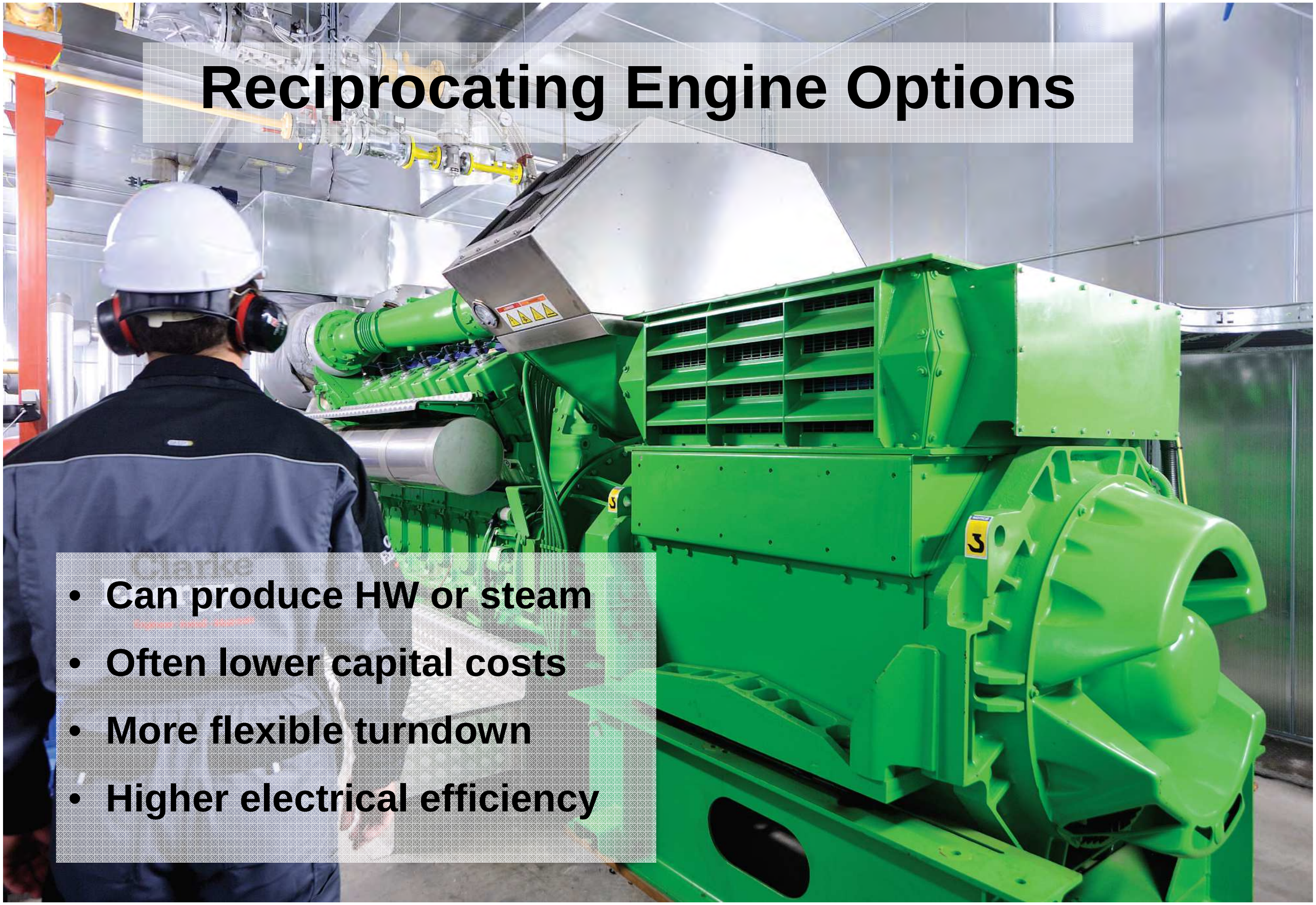
- Use condensing waste heat recovery (when using CO_2)
- Gas treatment is required
  - Oxidizing catalyst
  - SCR urea based NO_x scrubber
  - Sensors to test for NO_x, ethylene, unburned HC's
- Inherently CHP is:
  - a heating source: HW boiler
  - a source of electric power
  - the best "Energy Efficiency" technology
  - also a source of CO_2 and H_2O

What does CHP look like?

Combustion Gas Turbine

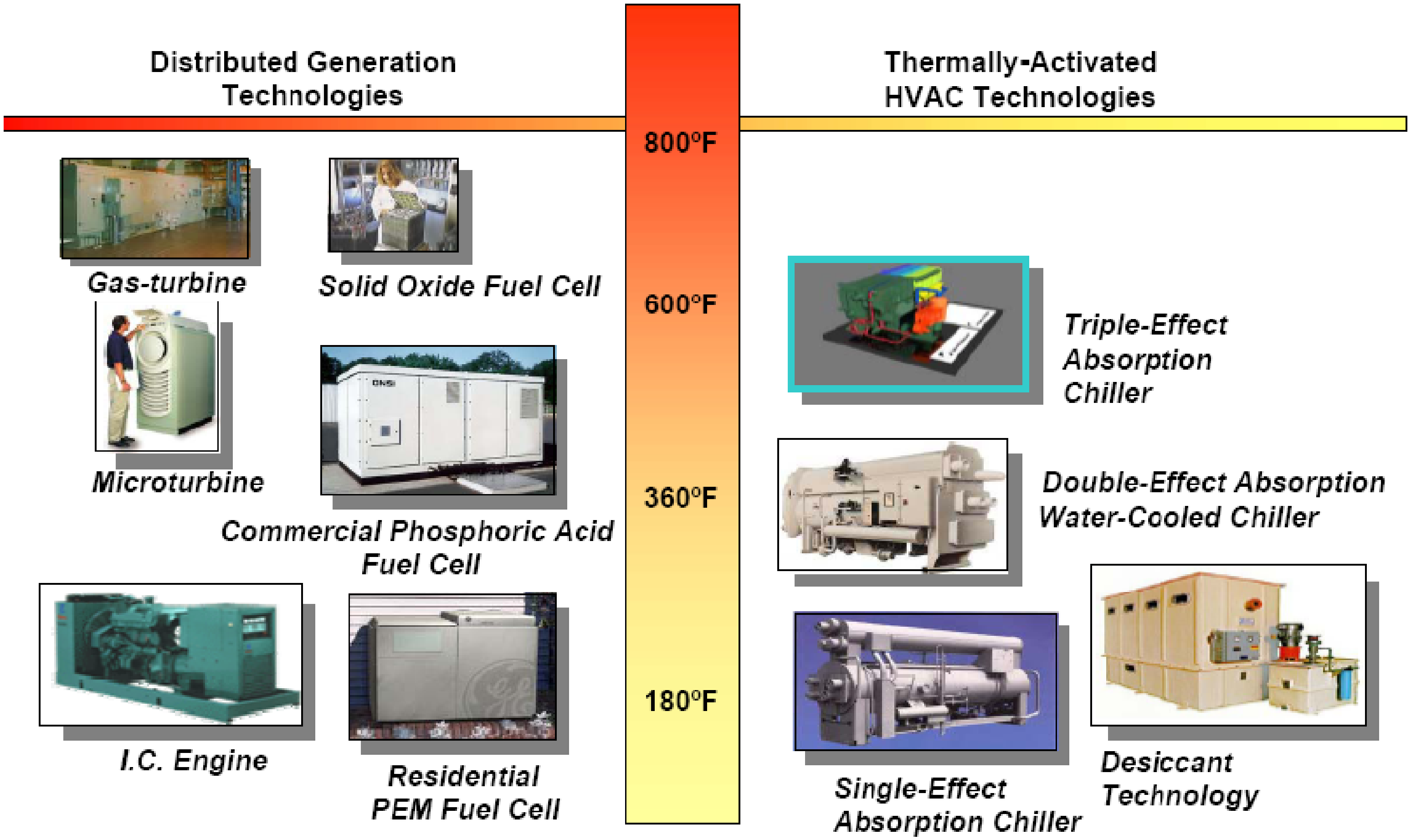


Reciprocating Engine Options



- Can produce HW or steam
- Often lower capital costs
- More flexible turndown
- Higher electrical efficiency

Thermally Driven Cooling (A/C)



Recoverable Energy Quality (Temperature) and HVAC Technology Match www.understandingCHP.com

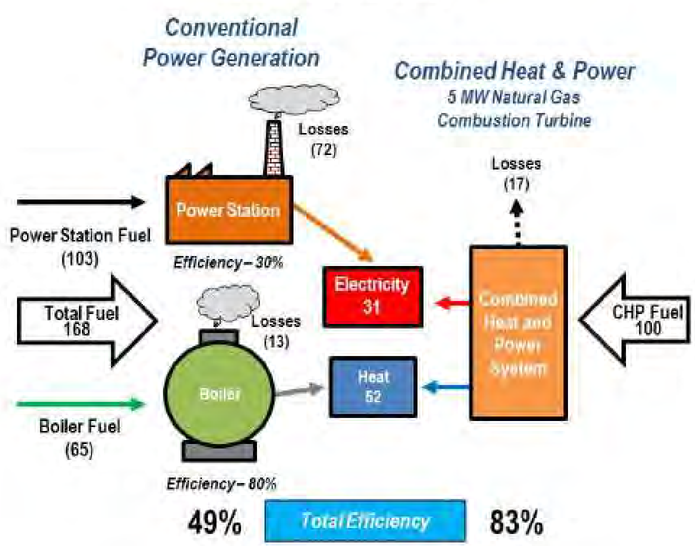
Understanding CHP | ESC Energy Solutions Center

What is CHP

Combined Heat and Power (CHP), Cogeneration, also known as on-site power generation, Distributed Generation (DG) and others, is the simultaneous production of electricity and useful 'waste' heat. Any facility that has significant thermal load requirements could be a technical fit for CHP. The economic fit will depend on electric cost of electricity, how closely the thermal demand matches the thermal production, and the installation complexity (project first cost).

Today, energy efficiency and environmental impacts are on everyone's mind. Understanding the real costs of the energy we consume in our buildings is also very important. CHP efficiency captures the energy content of both electricity and usable heat and is the net electrical output plus the net useful thermal output of the CHP system divided by the fuel consumed in the production of electricity and heat.

CHP Efficiencies



Ready packaged heat recovery modules are available to easily incorporate into your system to provide hot water or steam for your facility.

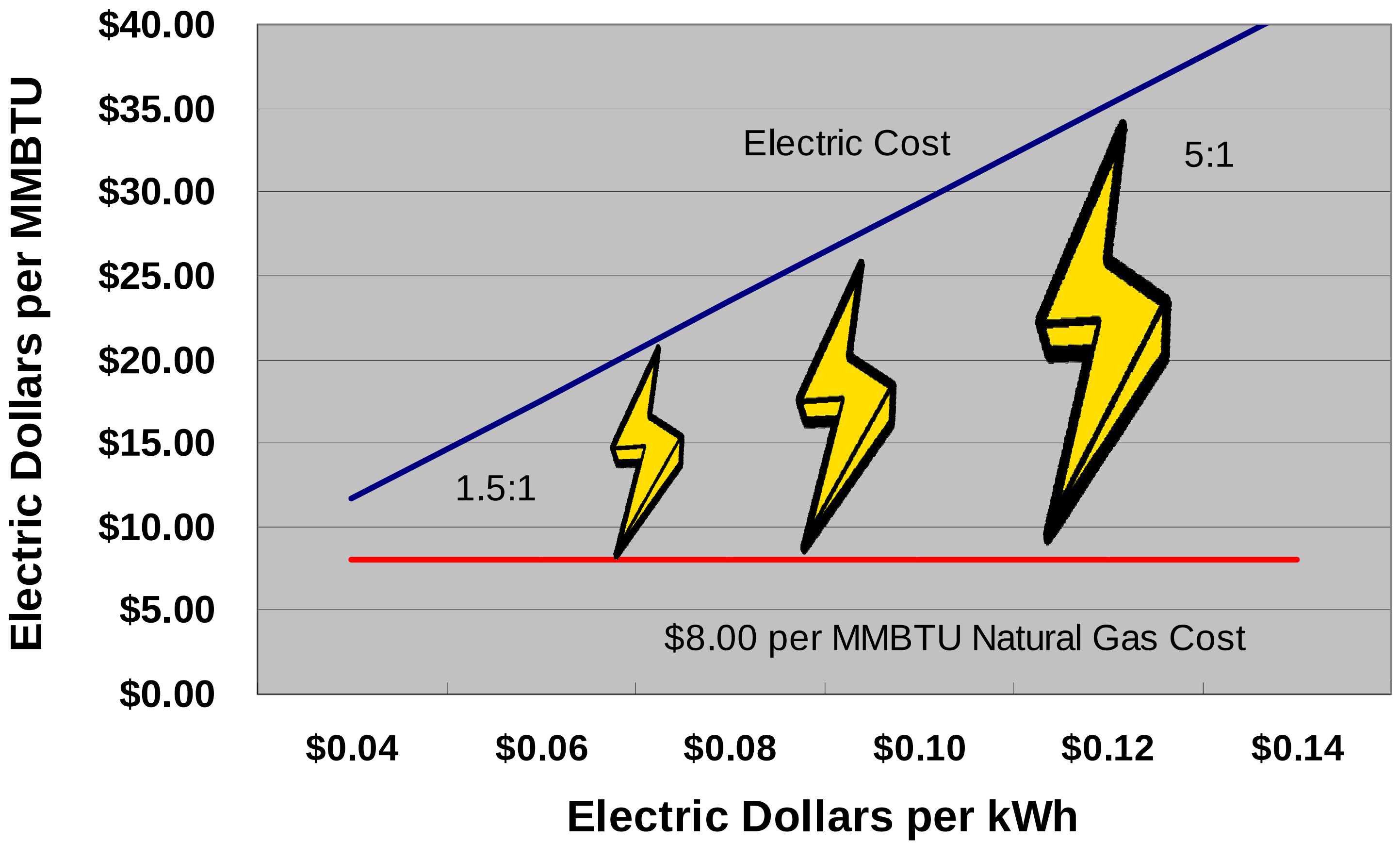
Ready packaged heat recovery modules are available to easily incorporate into your system to provide hot water or steam for your facility.

This various technologies are covered in more detail in the following sections:

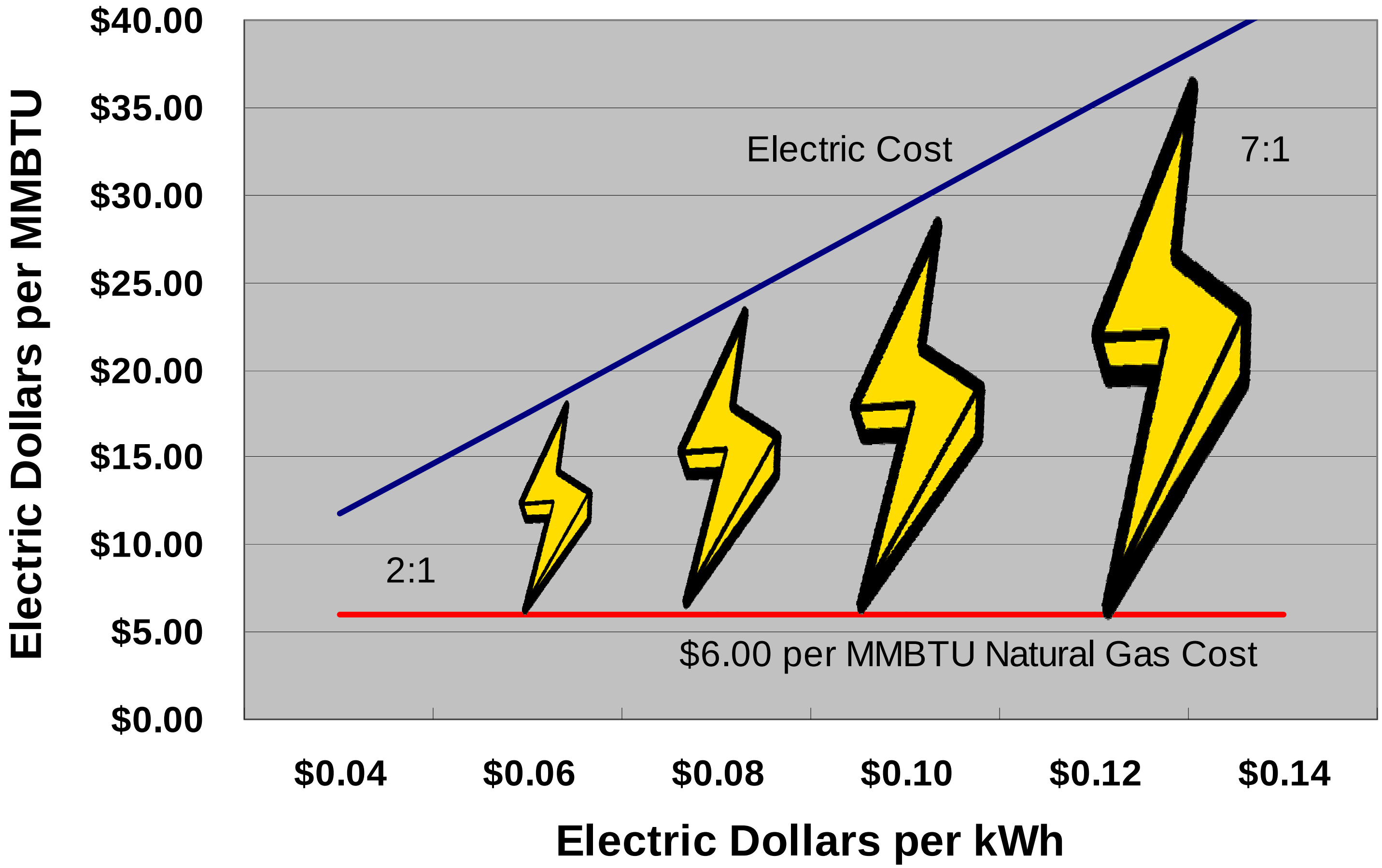
- Internal Combustion (Reciprocating) Engines
- Microturbines
- Fuel Cells
- Combustion Turbines
- Steam Turbine
- Combined Cycle
- Micro CHP

Click for Video

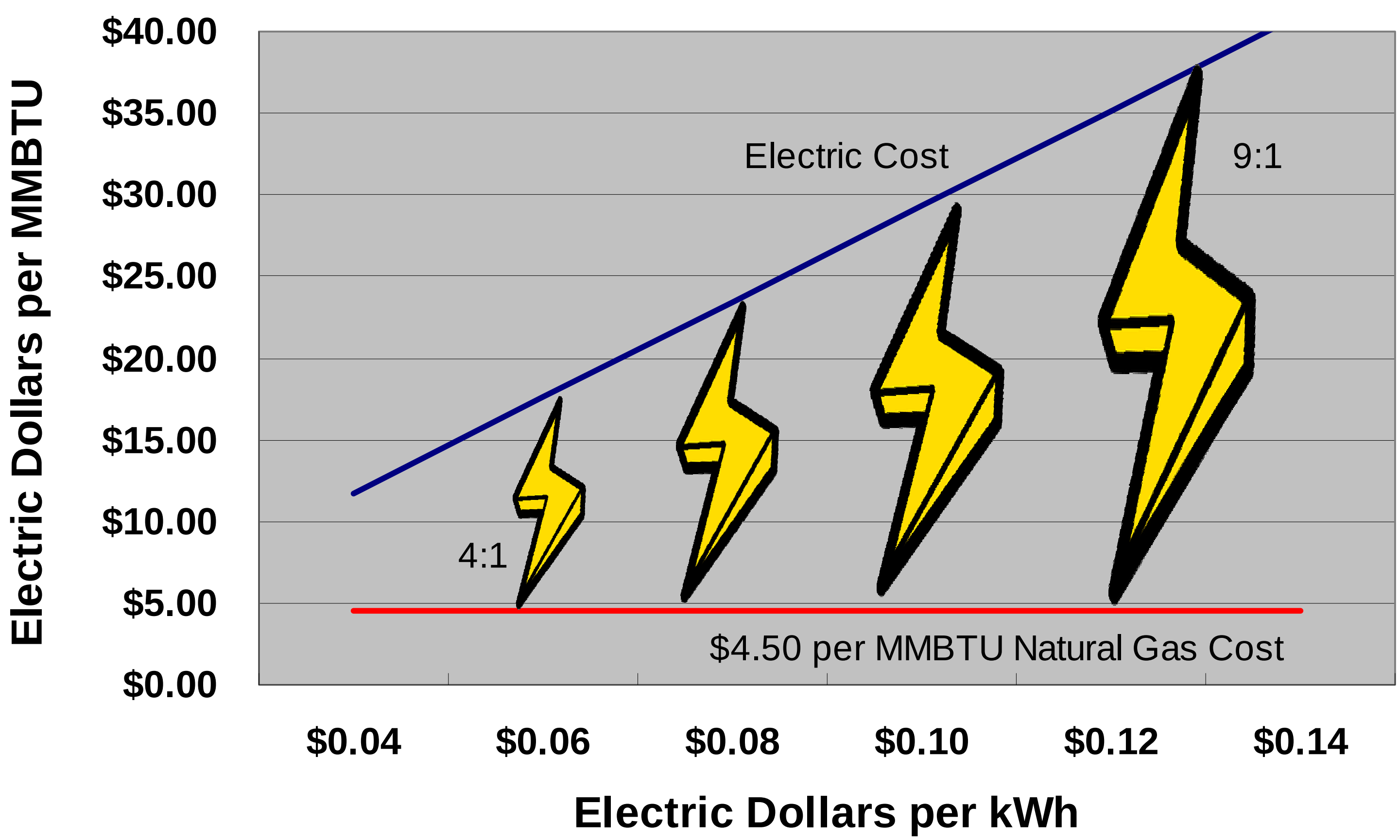
Spark Spread - $8 Gas



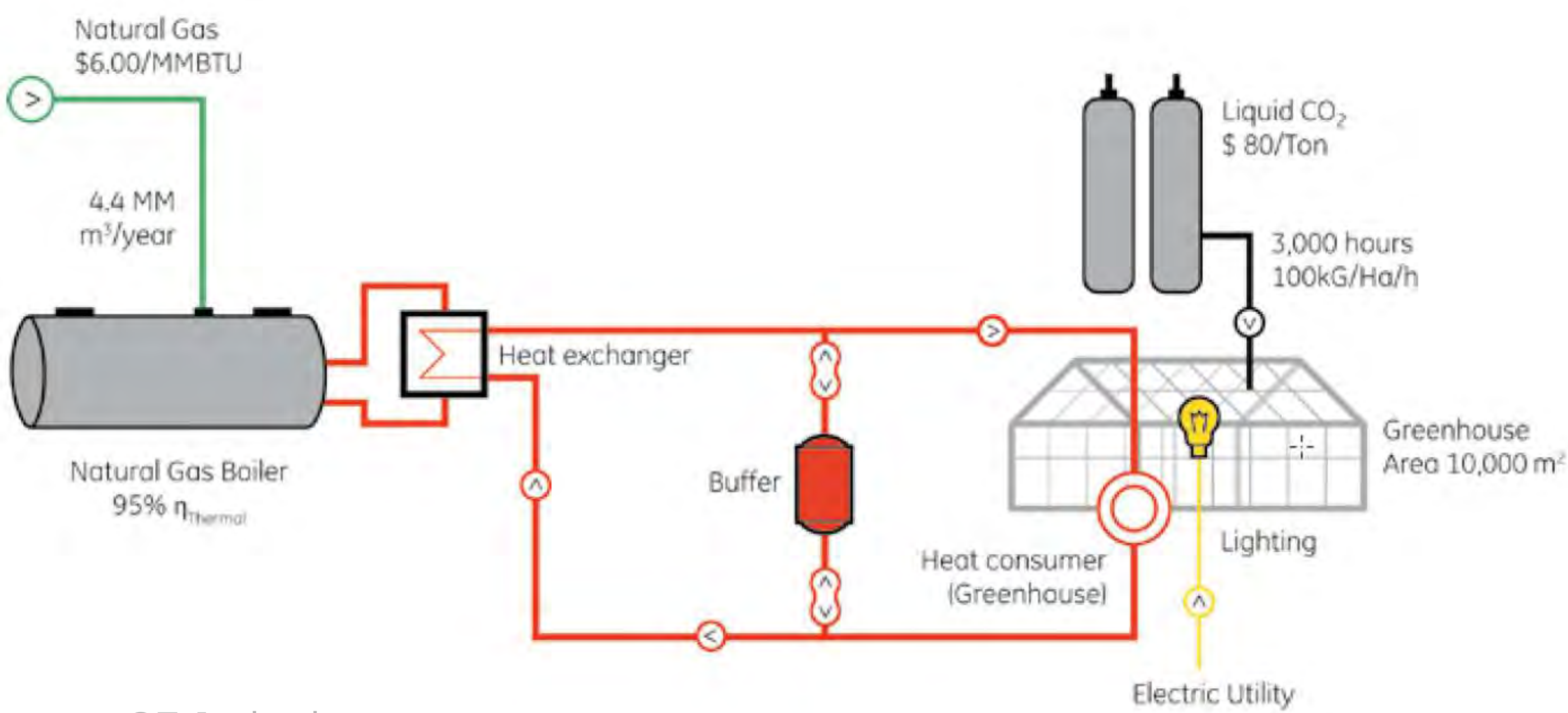
Spark Spread - $6 Gas



Spark Spread - $4.50 Gas

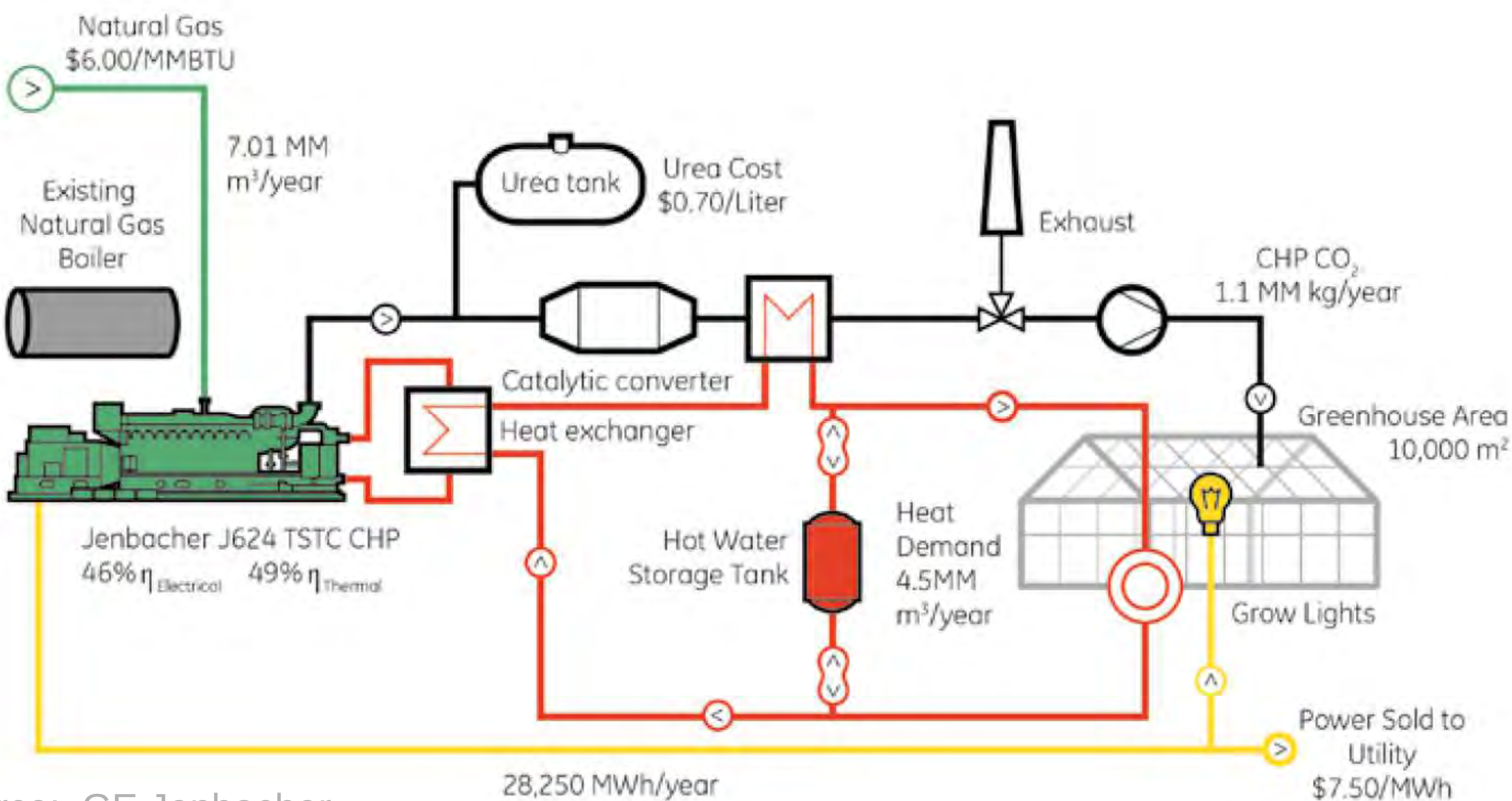


Boiler and Liquid CO2 Supplementation

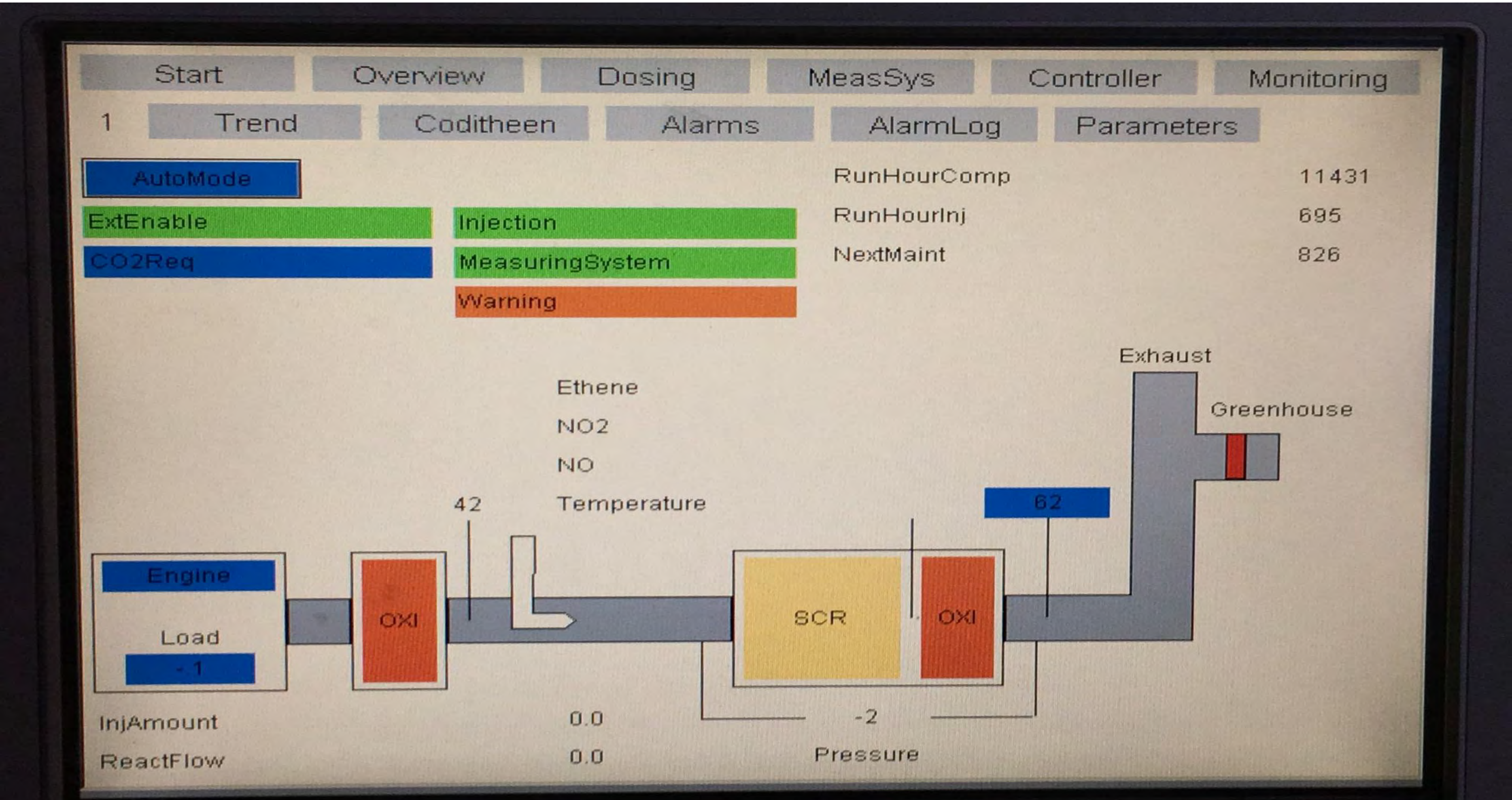


Source: GE Jenbacher

CHP System (Combined Heat and Power)



Source: GE Jenbacher

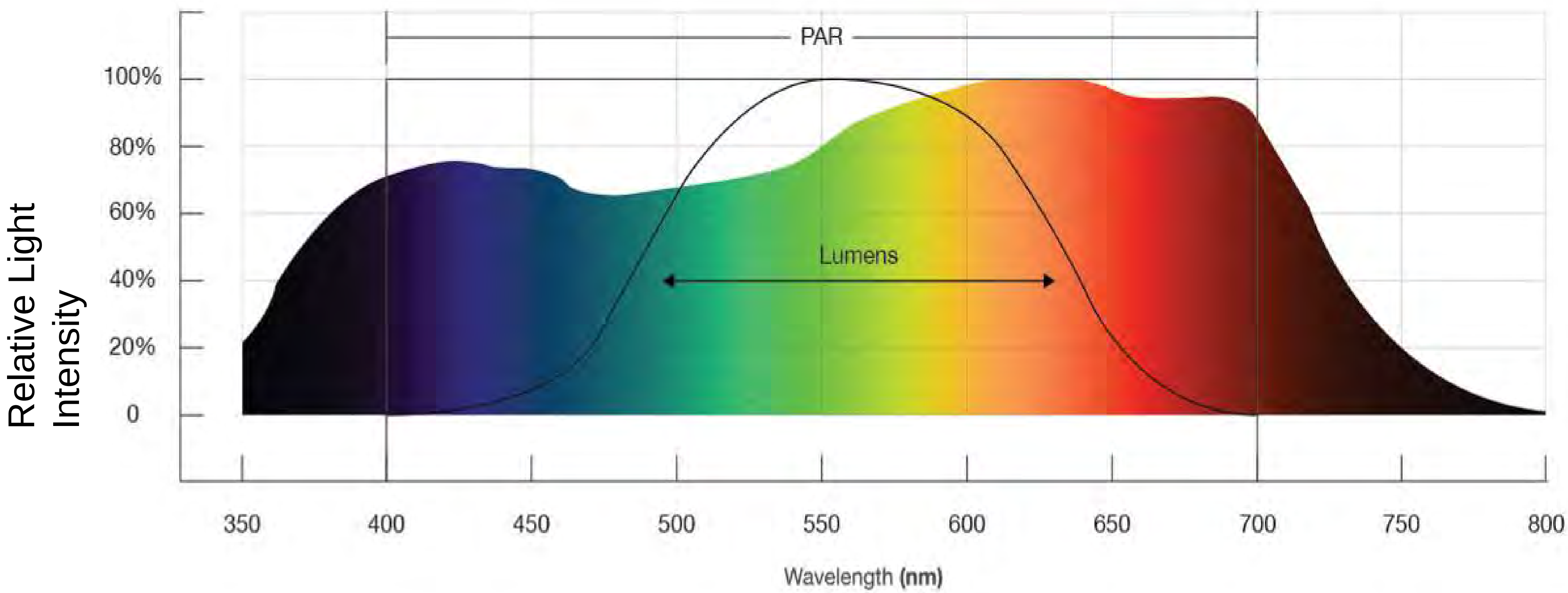


Source: GE Jenbacher system panel at Great Northern tomato grower, ONT, Canada

Lighting

- Natural light
  - Maximize use of natural light !
  - For indoor grow rooms, consider skylight tubes
- Artificial light sources
  - HPS (single and double ended)
  - MH (pulse start and ceramic)
  - LED

Photosyntheticly Active Radiation 400nm to 700nm



Case Studies

- Howling Tomatoes – Camarillo, CA
- Great Northern (Tomatoes) – Kingsville, ONT
- Coldwater Municipal – Coldwater, MI

Houweing Tomatoes

- 125 acre greenhouse
- Camarillo, California (north of Los Angeles)
- Three reciprocating natural gas engines
  - Over 40% electrical efficiency
  - Over 90% overall efficiency
- 13 MW total with excess power exported to grid
  - condensing waste heat exchanger
- Natural Gas CHP: four products utilized
  - electricity
  - heating
  - CO_2 exhaust (treated for use in greenhouse)
  - Condensed H_2O (treated for use in hydroponics)

Houweling's
Laguna Rd
© 2018 Google
202 ft
Google

Houweling Tomatoes - California

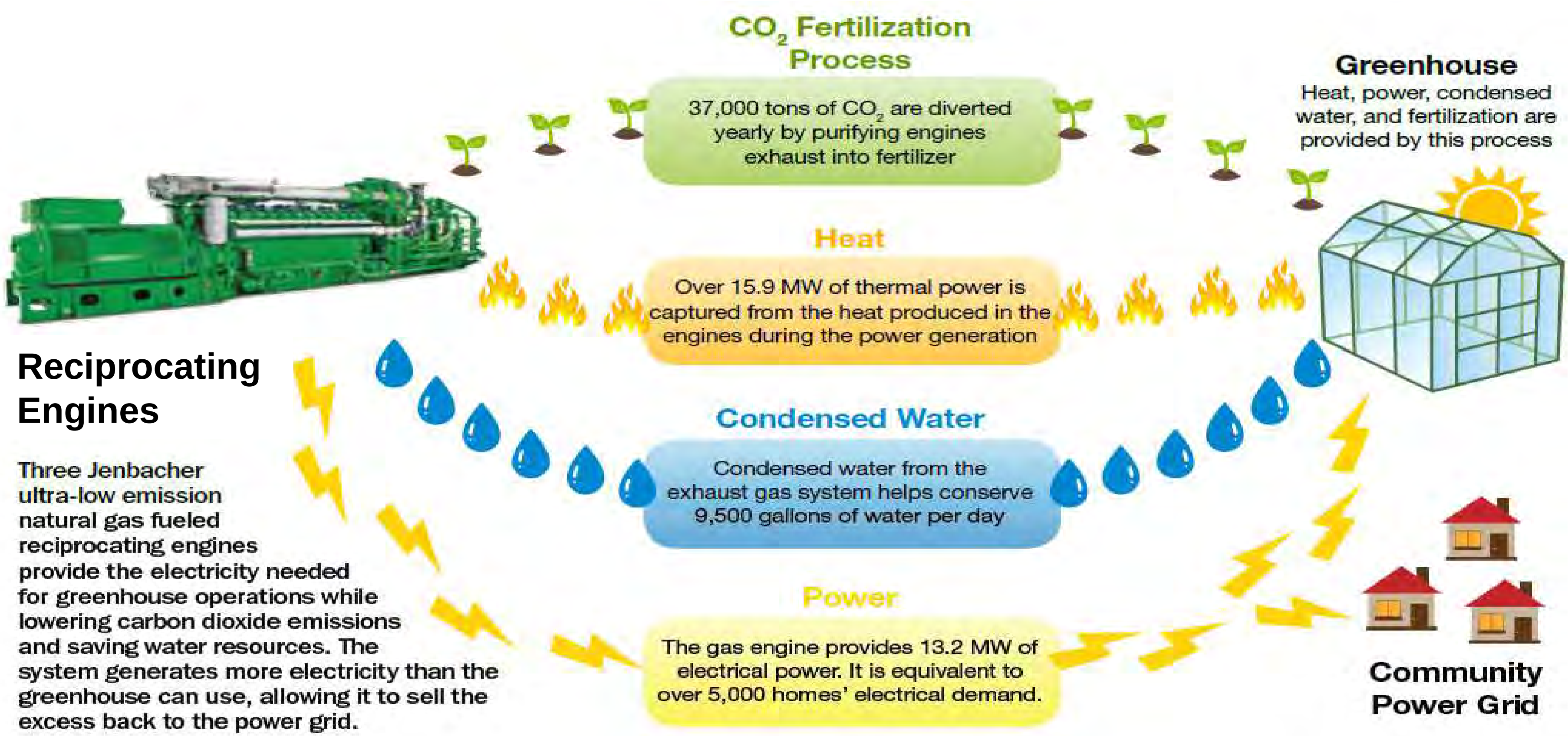


Image: Southern California Gas

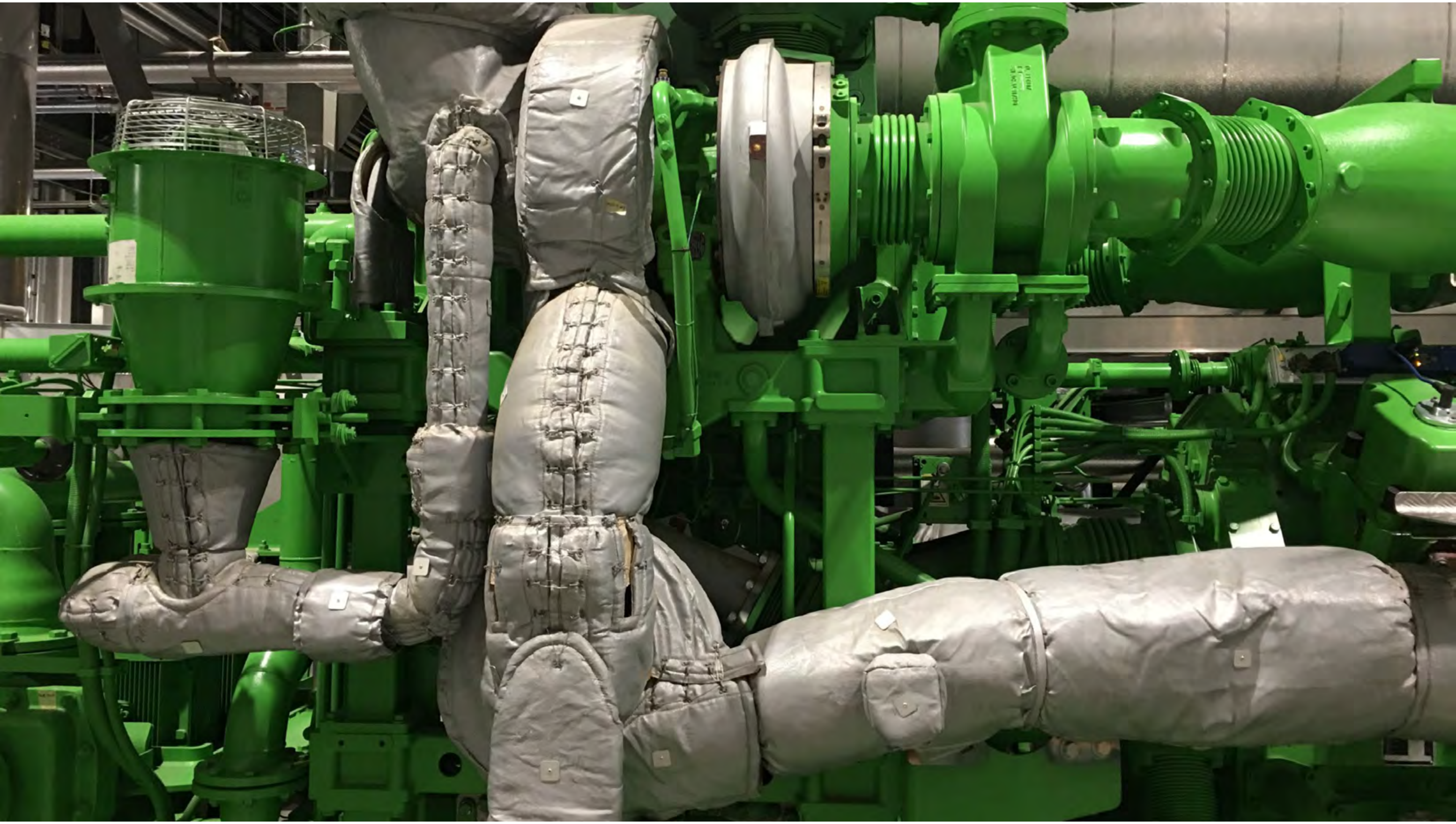
- Kingsville, ONT, Canada
- 50 acres of hydroponics tomatoes
- 5 acres under HPS lighting
- 12 MW electric CHP system
  - Sells electricity to Ontario Power Authority
- Uses mainly heat and CO_2 on-site


CAUTION

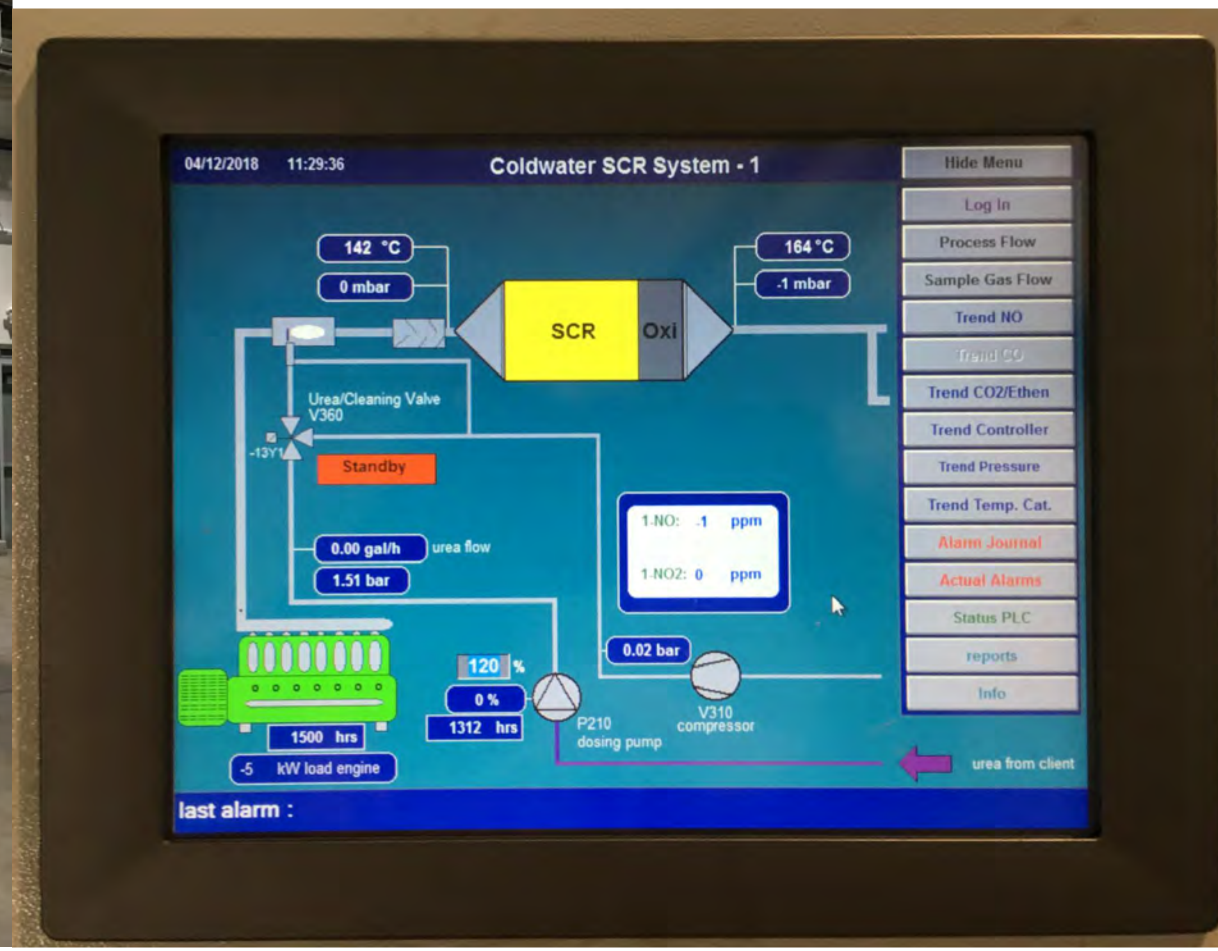

Grotop

- **Coldwater, MI (Municipal utility)**
- **System was installed adjacent to large commercial greenhouse operation for CHP & CO_2**
- **Currently operating as a peaking plant**
- **13 MW electric Jenbacher CHP system**


SUNSET
MAROA FARMS
270 NORTH FILLMORE RD.
270

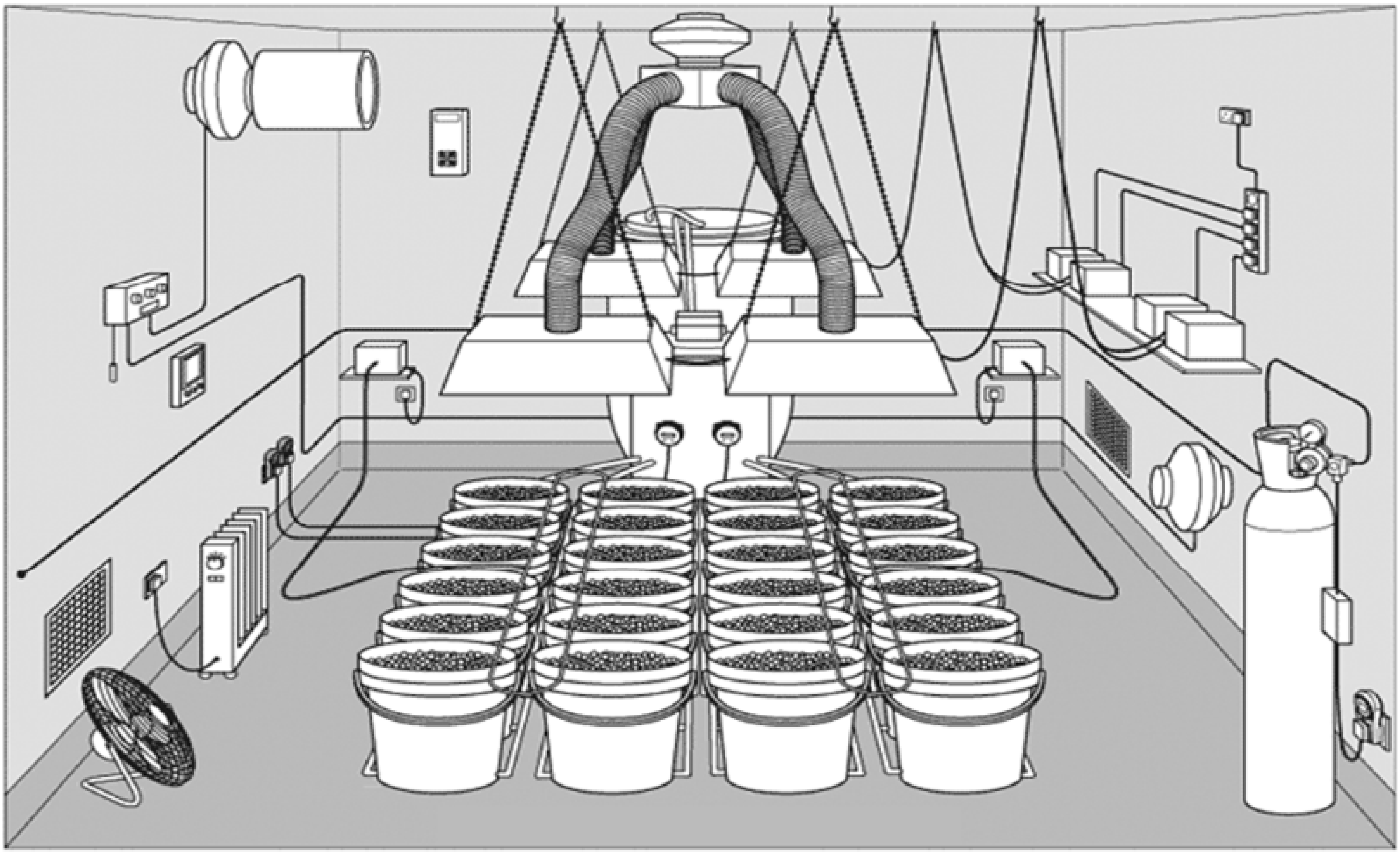


Urea Tank & Exhaust Treatment Controls

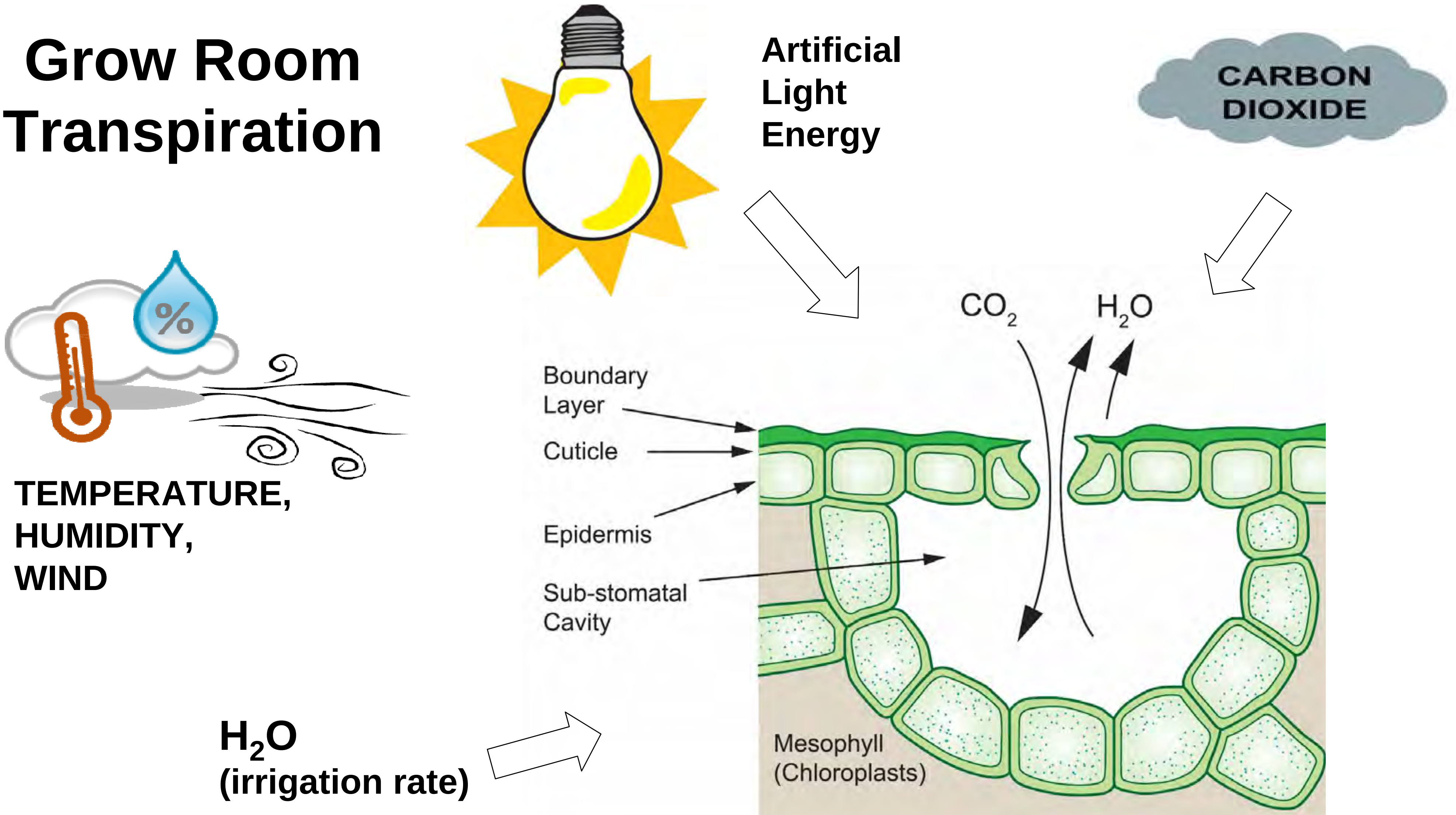


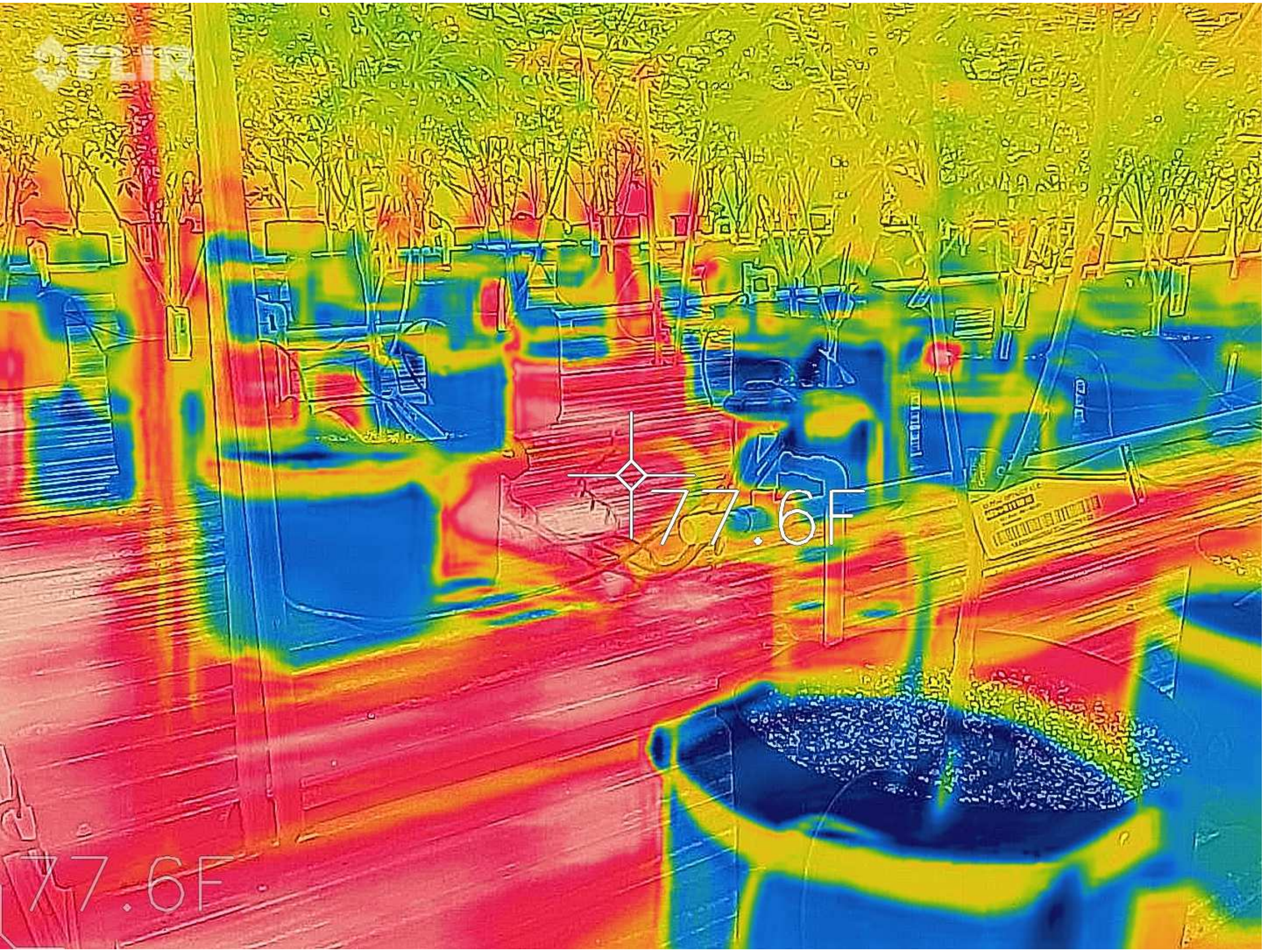
Liquid CO2 Tank

Next, the Emerging Cannabis Industry



Grow Room Transpiration

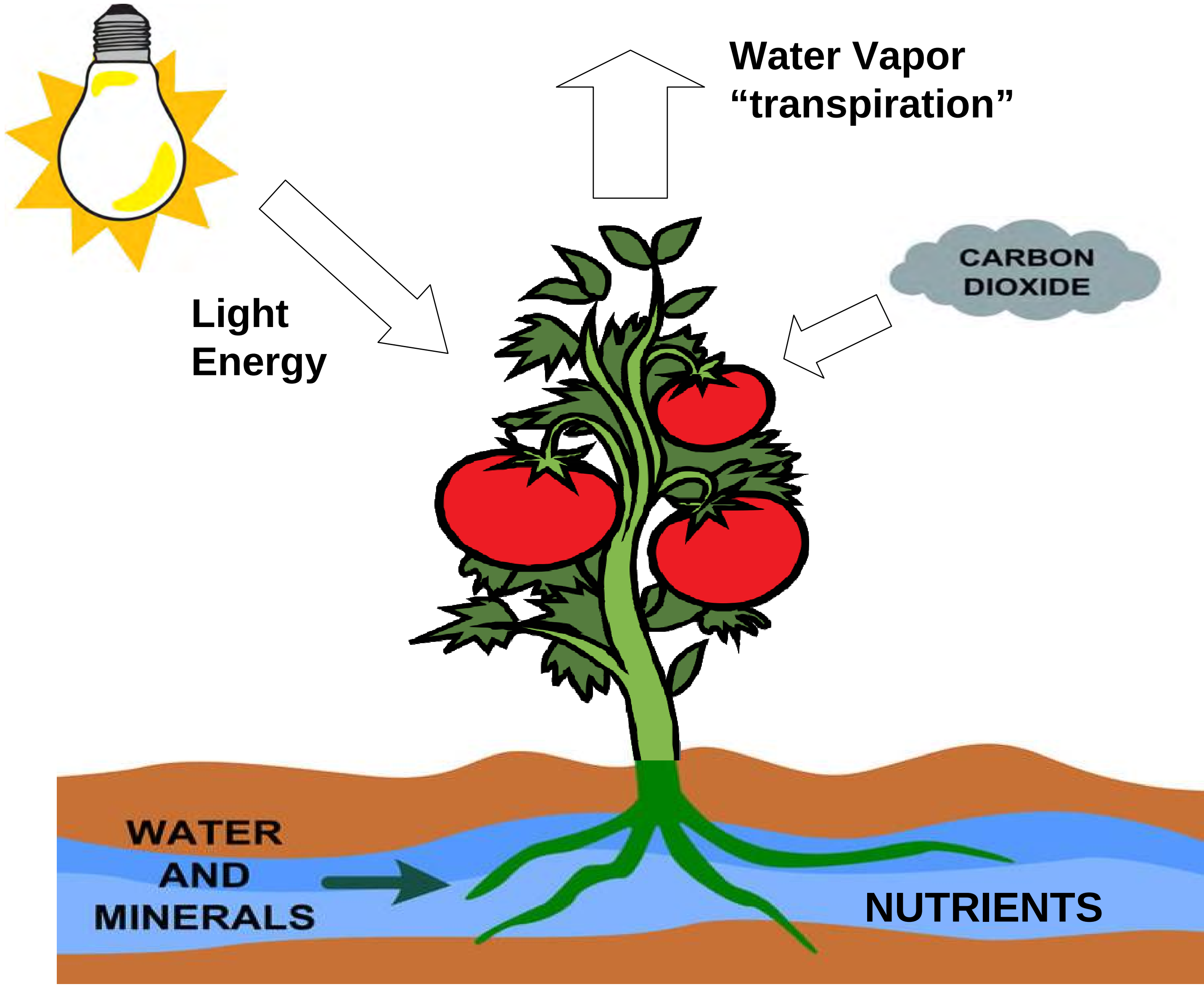




What is this *“Vapor Pressure Deficit”*

??

Vapor Pressure Deficit drives the nutrient flow



Growth Cycle

Source: John Knapp, Good Meds, Denver, CO
June 2018

GOOD MEDS

- Mother plants maintained in separate room
- Clones → transplant #1 into 5"x5" pots
  (18 Days)
- 5"x5"'s → transplant #2 into 3 gallon pots
  (3-4 weeks)
- 3 gallon → Mature to ~3ft tall
  (3-4 weeks)

VEG ROOM
18-6 LIGHT
SCHEDULE

- (~10 weeks) in flowering room → Harvest
  - Additional growth occurs during flowering
  - Mature watering rate ~0.5 to 1.0 gallon/day/plant

FLOWERING
12-12 LIGHT
SCHEDULE

Good Meds: Cannabis Operation – Warehouse Retrofit

John Knapp
Executive
Manager
and Owner

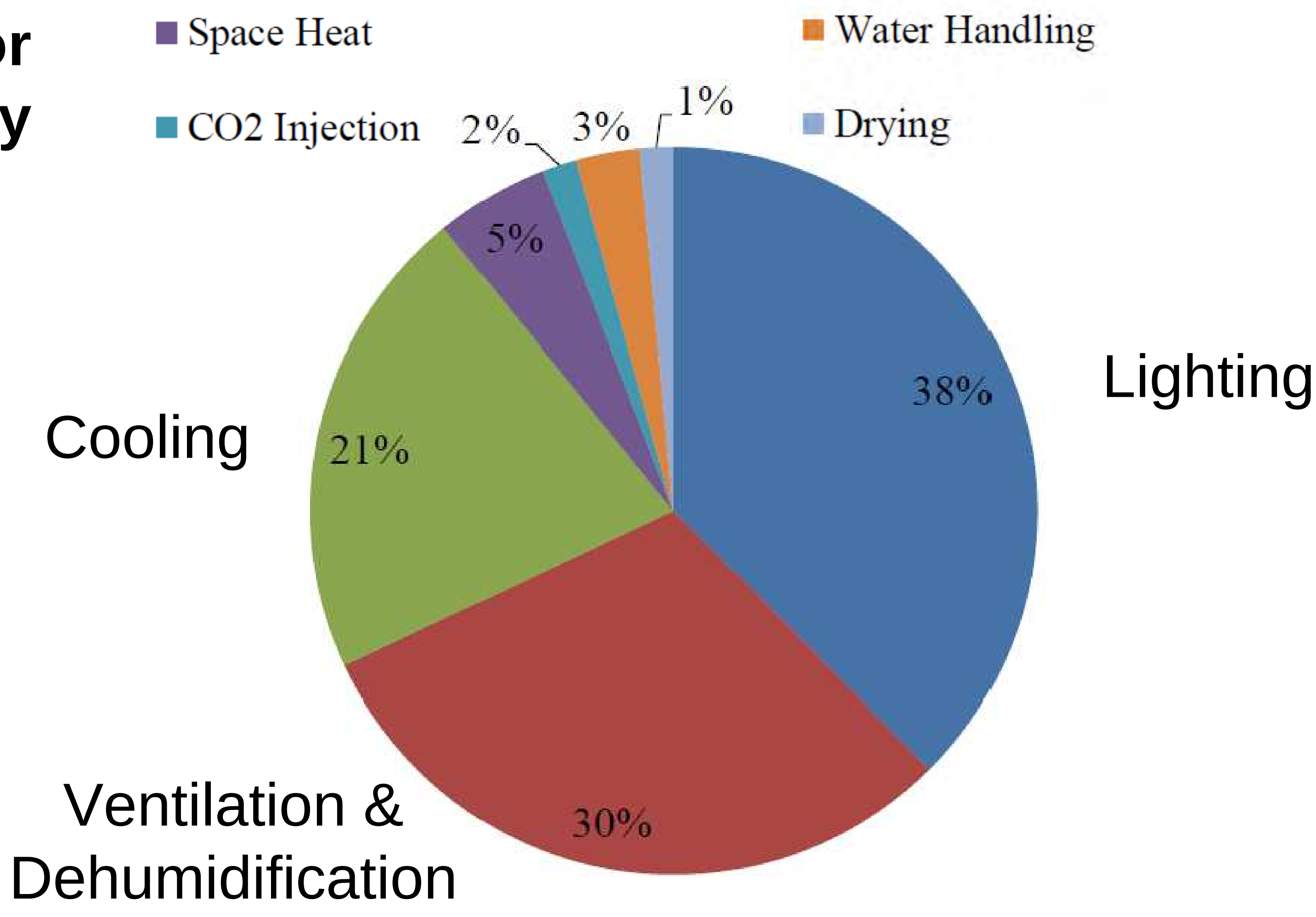
Good Meds
Denver, CO

GOOD MEDS


8
7
6
5
4
3

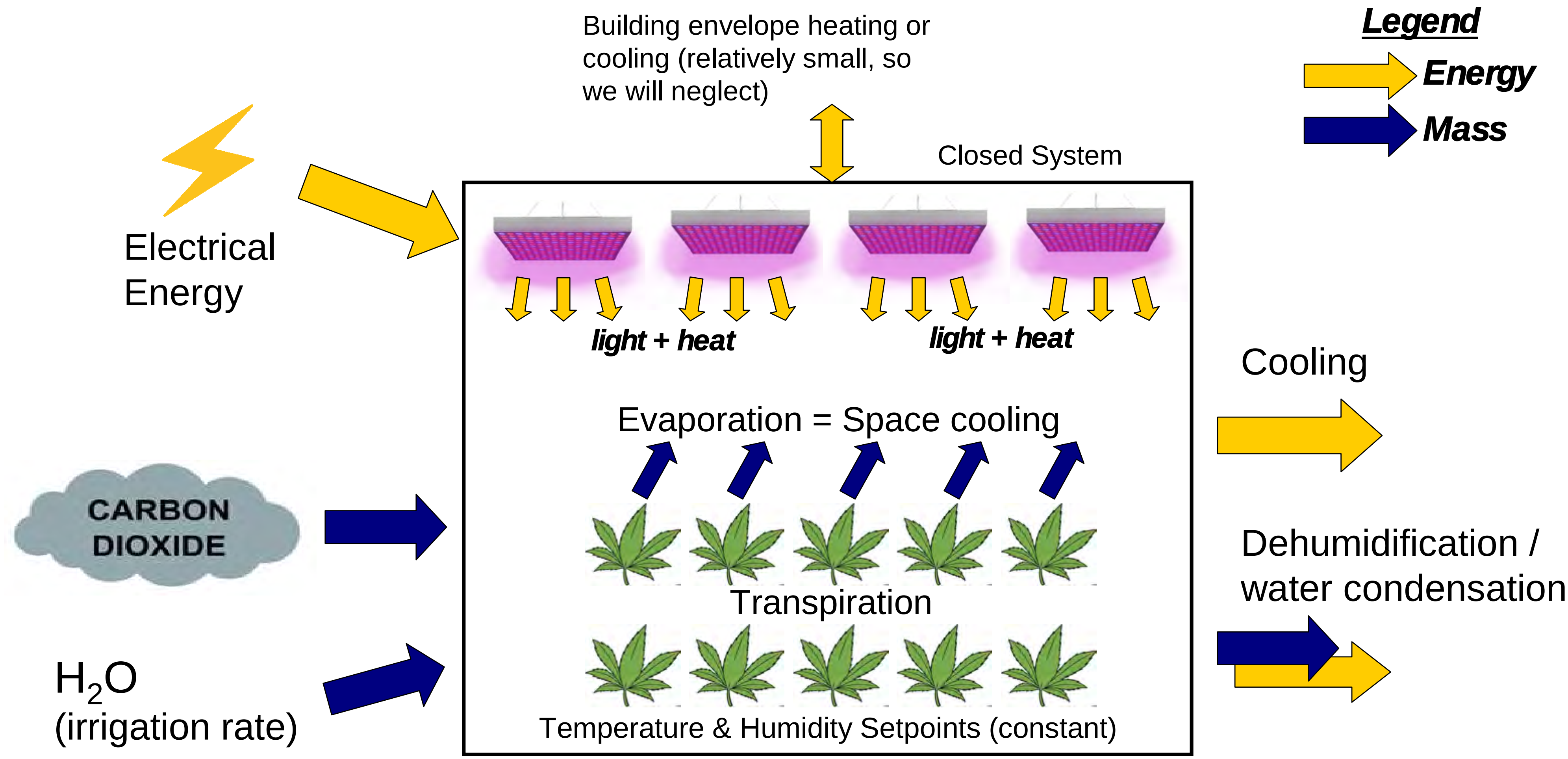

Flowering
Room
QUEST

Estimated Indoor Cannabis Energy Consumption



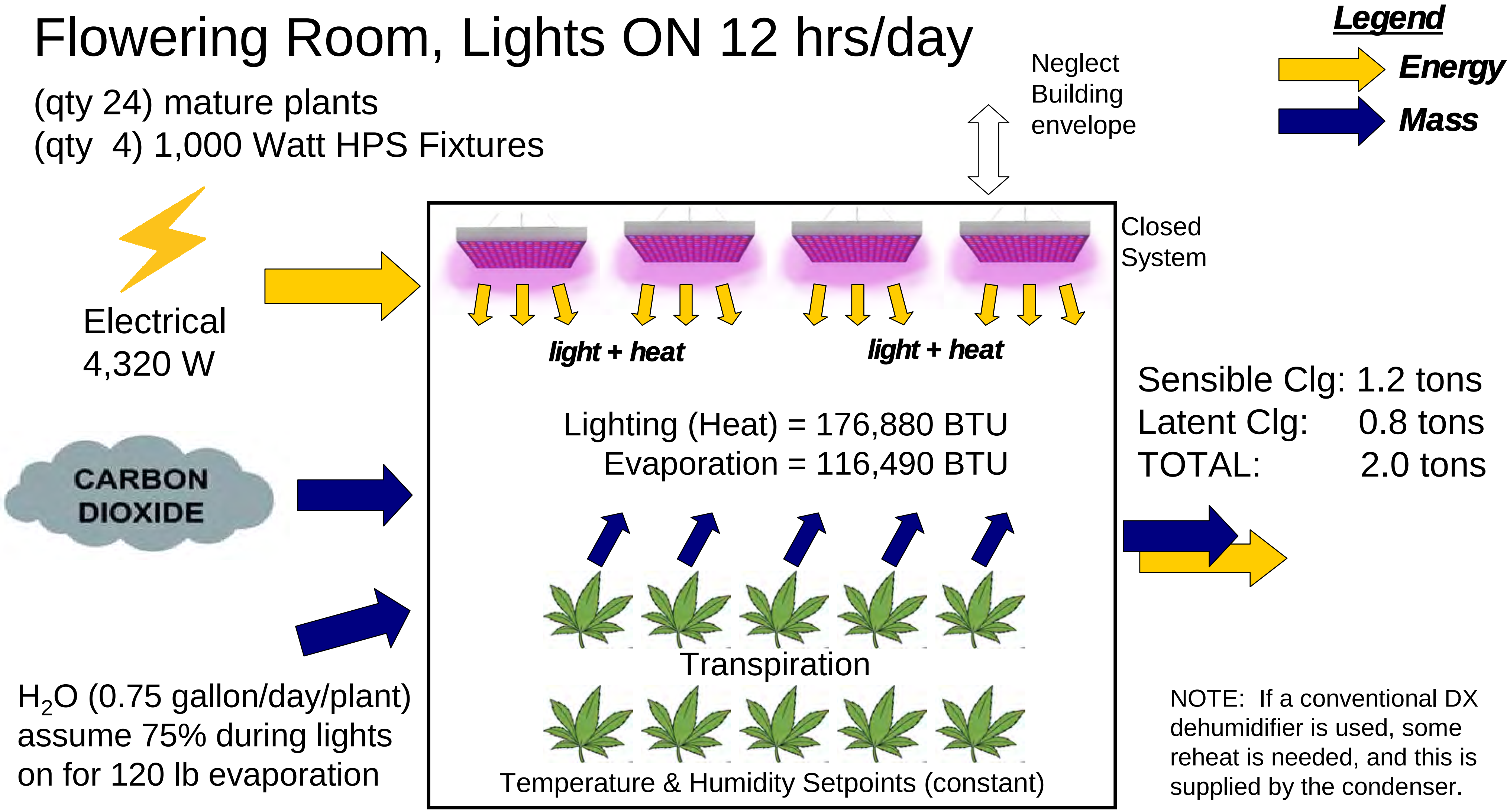
Source: Evan Mills, “The Carbon Footprint of Indoor Cannabis Production”, Energy Policy 46 (2012) 58–67.

Grow Room Mass and Energy Balance



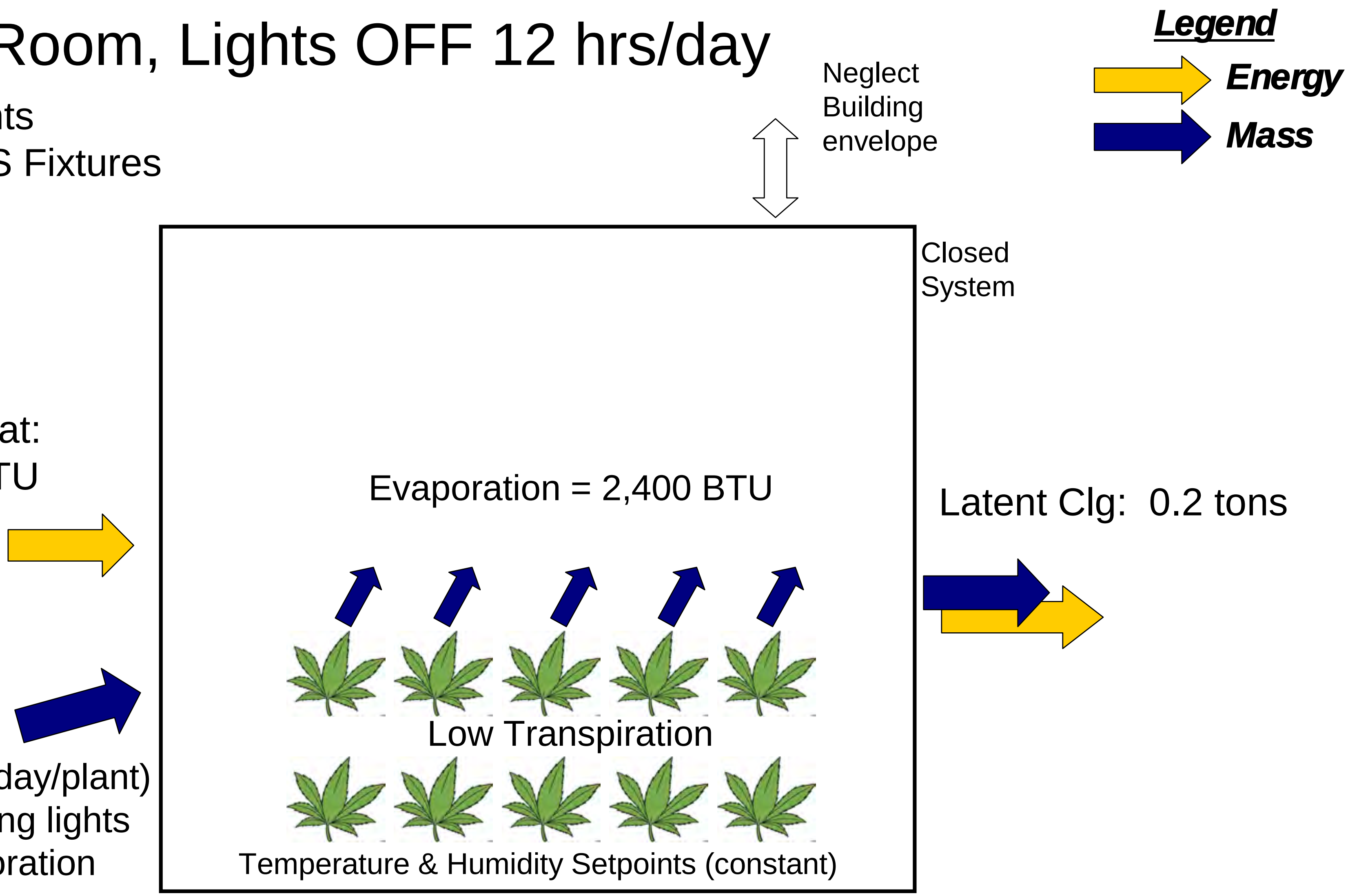
Flowering Room, Lights ON 12 hrs/day

(qty 24) mature plants
(qty 4) 1,000 Watt HPS Fixtures



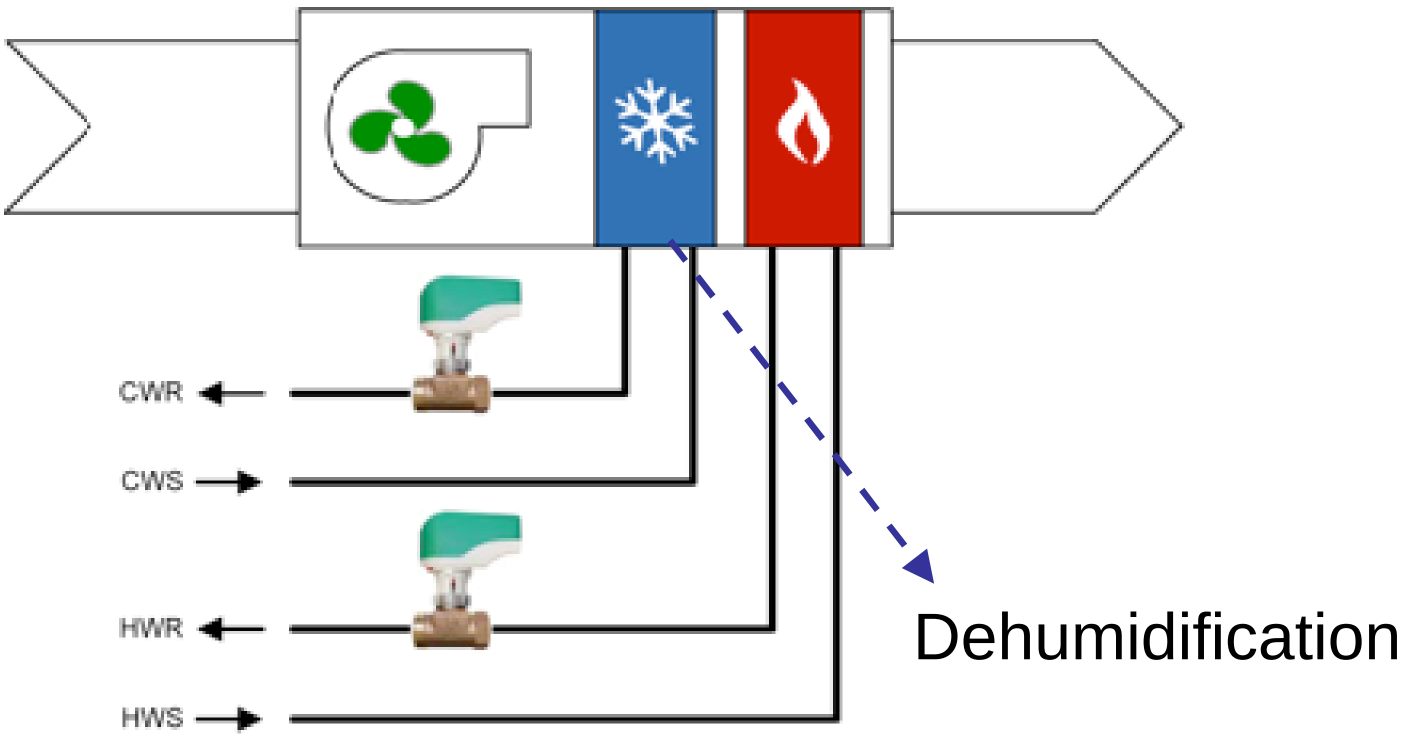
Flowering Room, Lights OFF 12 hrs/day

(24) mature plants
(4) 1,000W HPS Fixtures



H_2O (0.75 gallon/day/plant) assume 25% during lights on for 30 lb evaporation

Four Pipe Fan Coil



HVAC engineer needs to size to your room loads: coils, fan CFM, controls, etc…

Non-Ventilated Grow Room Energy Model

Light schedules and humidity estimates

Outputs

Indoor Grow Room Power and Cooling Model

Jim Leidel version 5/16/2017

Assumptions

Lighting and Space

8	sq foot per plant
65	W / sq foot for DE HPS
520	W / plant
1,000	W DE HPS light fixture
4	plants / 1,000 W DE HPS

One Michigan Class C cannabis license

1,500 plant class C license

Plant Counts

	Rooms	Plant/room	HPS/room	Plant total	HPS total
cloning room	1	300		300	n/a
veg rooms	2	300	75	600	150
flower rooms	4	150	38	600	150
TOTALS	**7**			**1,500**	**300**

Total Connected Lighting

300	1,000 W DE HPS fixtures (or metal halide for veg rooms)
12,000	square feet minimum area required
1,050	Watts total per fixture
30	kW estimated for cloning / mother room
345	kW total connected load for lighting for circuit sizing from grid

Watering Rate (per plant in veg and flower rooms)

0.5	gallons per plant per day for VEG RM	*4.0 pints / day*
1.5	gallons per plant per day for FLOWERING RM	*12.0 pints / day*
8.34	lb per gallon water (conversion factor)	

VEG ROOMS

70%	estimated % evaporation during LIGHTS ON for a 12/12 schedule
0.2433	est. lb evaporation per plant / hour LIGHTS ON for a 12/12 schedule
30%	estimated % evaporation during LIGHTS OFF for a 12/12 schedule
0.1043	est. lb evaporation per plant / hour LIGHTS OFF for a 12/12 schedule

FLOWERING ROOMS

70%	estimated % evaporation during LIGHTS ON for a 12/12 schedule
0.7298	est. lb evaporati[illegible] per plant / hour LIGHTS ON for a 12/12 schedule
30%	estimated % eva[illegible]ion during LIGHTS OFF for a 12/12 schedule
0.3128	est. lb evaporati[illegible]nt / hour LIGHTS OFF for a 12/12 schedule

15	ft ceilings
180,000	ft3 grow space air volu[illegible]
15%	additial grow room work[illegible] space
207,000	ft3 TOTAL room volume
13.8	ft3 / lb dry air specific volu[illegible]
15,000	lb mass of dry air, total in th[illegible]row volume

320	kW electrical input				
1,090,134	BTU/hr electrical input heating	72.68	BTU/hr/lb	1.211	BTU/lb per minute
728,082	BTU/hr evaporative cooling	48.54	BTU/hr/lb	0.809	BTU/lb per minute
750.6	lb H2O / hr evaporation	0.05	lb H2O/hr/lb	0.001	lb H2O/lb per minute
5,254,200	grains H2O / hr evaporation	[illegible]50.28	grains/hr/lb	5.838	grains H2O / lb per minute
362,052	BTU/hr net (positive = heating)	[illegible].14	BTU/hr/lb net	0.402	BTU/lb per minute net

Lighting Schedules

Hour	Time	CloneRM kW	[illegible]EG1 (18/6) [illegible]W	lb H2O	VEG2 (18/6) kW	lb H2O	FLWR1 (12/12) kW	lb H2O	FLWR2 (12/12) kW	lb H2O	FLWR3 (12/12) kW	lb H2O	FLWR4 (12/12) kW	lb H2O	Total kW	Total lb H2O
1	0:00	30.0	[illegible]	73.0	off	31.3	39.4	218.9	off	93.8	39.4	218.9	off	93.8	188	730
2	1:00	30.0	[illegible]	73.0	off	31.3	39.4	218.9	off	93.8	39.4	218.9	off	93.8	188	730
3	2:00	30.0	78[illegible]	73.0	off	31.3	39.4	218.9	off	93.8	39.4	218.9	off	93.8	188	730
4	3:00	30.0	78[illegible]	[illegible]3.0	off	31.3	39.4	218.9	off	93.8	39.4	218.9	off	93.8	188	730
5	4:00	30.0	78.8	[illegible]3.0	off	31.3	39.4	218.9	off	93.8	39.4	218.9	off	93.8	266	730
6	5:00	30.0	78.8	[illegible]3.0	off	31.3	39.4	218.9	off	93.8	39.4	218.9	off	93.8	188	730
7	6:00	30.0	[illegible]	[illegible]3.0	78.8	73.0	39.4	218.9	off	93.8	39.4	218.9	off	93.8	266	771
8	7:00	30.0	78.8	[illegible]3.0	78.8	73.0	39.4	218.9	off	93.8	39.4	218.9	off	93.8	266	771
9	8:00	30.0	78.8	73.0	78.8	73.0	39.4	218.9	off	93.8	39.4	218.9	off	93.8	266	771
10	9:00	30.0	78.8	73.0	78.8	73.0	39.4	218.9	off	93.8	39.4	218.9	off	93.8	266	771
11	10:00	30.0	78.8	73.0	78.8	73.0	39.4	218.9	off	93.8	39.4	218.9	off	93.8	266	771
12	11:00	30.0	78.8	73.0	78.8	73.0	39.4	218.9	off	93.8	39.4	218.9	off	93.8	266	771
13	12:00	30.0	78.8	73.0	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	266	771
14	13:00	30.0	78.8	73.0	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	266	771
15	14:00	30.0	off	31.3	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	188	730
16	15:00	30.0	off	31.3	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	188	730
17	16:00	30.0	off	31.3	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	188	730
18	17:00	30.0	off	31.3	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	188	730
19	18:00	30.0	off	31.3	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	188	730
20	19:00	30.0	off	31.3	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	188	730
21	20:00	30.0	78.8	73.0	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	266	771
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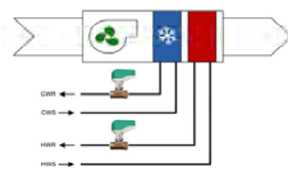
24	23:00	30.0	78.8	73.0	78.8	73.0	off	93.8	39.4	218.9	off	93.8	39.4	218.9	266	771
			1,417.5 kWh/day	1,501.2 lb/day	1,417.5 kWh/day	1,501.2 lb/day	472.5 kWh/day	3,753.0 lb/day	472.5 kWh/day	3,753.0 lb/day	472.5 kWh/day	3,753.0 lb/day	472.5 kWh/day	3,753.0 lb/day	5,524 kWh/day	18,014 lb/day
																750.6 lb/hr avg



System Notes:

1. the proposed system is a hot water & chilled water hydronic
2. a four pipe fan coil (shown here) is the terminal unit for space clg, htg & dehumidificaiton
3. the CHP unit supplies power and heat and a hot water buffer tank is recommended
4. abosorption chillers use hot water to make chilled water
5. a low chilled water setpoint in the range of 38 deg F is recommended for strong dehumid.
6. an experienced HVAC engineer needs to size the FC's properly for proper dehumid.
7. redundancy is recommended in the number of CHP units AND chillers
8. a closed circuit cooling tower is recommended for low maintenace
9. closed circuit cooling tower should be a hybird evaporaitve / dry type
10. a hot water boiler should be included to allow for redundancy and peak reheat/chiller loads

Lighting Loads to Size CHP			Notes:
Lighting total connected load	345	kW total	for electr
Max Lighting Power Load	266	kW max	largest v
Add'l Power (pumps, fans, clon[illegible])	20%		increase
Add'l Power (pumps, fans, clone[illegible]	53	kW	
Total Est. Power	**320**	**kW**	total CH
CHP units (sized to load)	2		recomm
CHP uint size each	160	kW	
Extra redundant unit (+1)	160	kW	one add
Total Number of CHP units	3		number
CHP unit size each	160		
Total CHP plant capacity (including +1)	**479**		total CH
CHP Plant Thermal Output Calculations			
CHP unit electrical output	320	kW	
CHP unit electrical efficiency	35.0%		
CHP natural gas fuel input	913	kW	
CHP natural gas input	3.11	MMBTU/hr	natural g
CHP natural gas input	3.11	MCF/hr	natural g
CHP thermal efficiency	45.0%		assume
CHP thermal output	1.40	MMBTU/hr	hot wate
typical single effect absorption chiller	0.70	COP	coeficier
max possible absorption chiller capacity	0.98	MMBTU/hr	
max possible absorption chiller capacity	82	tons	max chil
Lighting + Dehumidification Loads to Size Absorption Chiller			
Sensible heating from lighting	320	kW	all electr
Sensible heating from lighting	1,090,134	BTU / hr	
Avg. irrigation rate	750.6	lb / hr water	average
Latent heat of evaporation	970	BTU / lb	unt conv
Evaporative cooling from water	728,082	BTU / hr	total eva
Net sensible heating (lights - evap.)	362,052	BTU / hr	net cooli
Net sensible heating (lights - evap.)	30	tons	one ton
Dehumidification chilled water load	728,082	BTU / hr	from abc
Dehumidification chilled water load	61	tons	
Total chilled water load	**91**	**tons**	
Number of chillers sized to meet load	2		
Chiller size each (absorption)	45	tons	
Extra redundant unit (+1)	45	tons	
Total Numbe of Chillers	3		
Chiller size each (absorption)	45	tons	
Total absorption chiller plant capacity	**136**	**tons**	
Boiler Sizing			
Backup boiler (sized to run one absorber)	778,667	BTU / hr	currently
	0.78	MMBTU/hr	
	0.78	MCF/hr	
Redundancy boiler for absorbers	1.56	MMBTU/hr	
Est approx. boiler size	1.00	MCF/hr	

Inputs: Light fixture count, wattage, and watering rates

Indoor Grow Room Power and Cooling Model

Jim Leidel version 5/16/2017

Model for One Michigan Class C License of 1,500 Plants

Assumptions

Lighting and Space

8	sq foot per plant
65	W / sq foot for DE HPS
520	W / plant
1,000	W DE HPS light fixture
4	plants / 1,000 W DE HPS

One Michigan Class C cannabis license

1,500 plant class C license

Plant Counts

	Rooms	Plant/room	HPS/room	Plant total	HPS total
cloning room	1	300		300	n/a
veg rooms	2	300	75	600	150
flower rooms	4	150	38	600	150
TOTALS	**7**			**1,500**	**300**

Total Connected Lighting

300	1,000 W DE HPS fixtures (or metal halide for veg rooms)
12,000	square feet minimum area required
1,050	Watts total per fixture
30	kW estimated for cloning / mother room
345	kW total connected load for lighting for circuit sizing from grid

Watering Rate (per plant in veg and flower rooms)

0.5	gallons per plant per day for VEG RM	*4.0 pints / day*
1.5	gallons per plant per day for FLOWERING RM	*12.0 pints / day*
8.34	lb per gallon water (conversion factor)	
VEG ROOMS		
70%	estimated % evaporation during LIGHTS ON for a 12/12 schedule	
0.2433	est. lb evaporation per plant / hour LIGHTS ON for a 12/12 schedule	
30%	estimated % evaporation during LIGHTS OFF for a 12/12 schedule	
0.1043	est. lb evaporation per plant / hour LIGHTS OFF for a 12/12 schedule	
FLOWERING ROOMS		
70%	estimated % evaporation during LIGHTS ON for a 12/12 schedule	
0.7298	est. lb evaporation per plant / hour LIGHTS ON for a 12/12 schedule	
30%	estimated % evaporation during LIGHTS OFF for a 12/12 schedule	
0.3128	est. lb evaporation per plant / hour LIGHTS OFF for a 12/12 schedule	

Model for One Michigan Class C License of 1,500 Plants

Lighting Schedules			18/6		18/6		12/12		12/12		12/12		12/12			
		CloneRM	VEG1		VEG2		FLWR1		FLWR2		FLWR3		FLWR4			
Hour	Time	kW	kW	lb H2O	kW	lb H2O	kW	lb H2O	kW	lb H2O	kW	lb H2O	kW	lb H2O	Total kW	Total lb H2O
1	0:00	30.0	78.8	73.0	off	31.3	39.4	218.9	off	93.8	39.4	218.9	off	93.8	188	730
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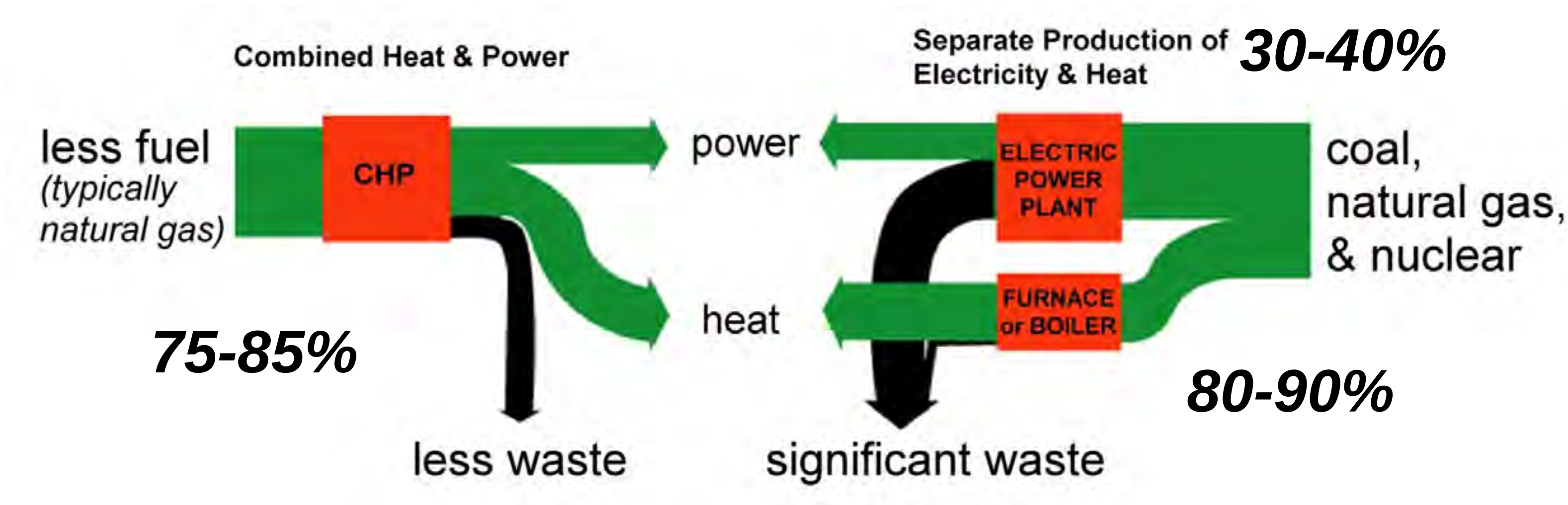
			1,417.5 kWh/day	1,501.2 lb/day	1,417.5 kWh/day	1,501.2 lb/day	472.5 kWh/day	3,753.0 lb/day	472.5 kWh/day	3,753.0 lb/day	472.5 kWh/day	3,753.0 lb/day	472.5 kWh/day	3,753.0 lb/day	5,524 kWh/day	18,014 lb/day
																750.6 lb/hr avg

Model for One Michigan Class C License of 1,500 Plants

			Notes:
Lighting Loads to Size CHP			
Lighting total connected load	345	kW total	for electrical circuit sizing, NOT CHP sizing
Max Lighting Power Load	266	kW max	largest value from Total kW column X from lighting schedules
Add'l Power (pumps, fans, clone rm., etc...)	20%		increase percentage for more safety factor
Add'l Power (pumps, fans, clone rm., etc...)	53	kW	
Total Est. Power	**320**	**kW**	total CHP load under full production, to minimum CHP capacity
CHP units (sized to load)	2		recommend 2-3 units minimum for redundancy
CHP uint size each	160	kW	
Extra redundant unit (+1)	160	kW	one additional unit for maintenance and redundancy
Total Number of CHP units	3		number of CHP units (the base number +1)
CHP unit size each	160		
Total CHP plant capacity (including +1)	**479**		total CHP plant capacity including the +1
CHP Plant Thermal Output Calculations			
CHP unit electrical output	320	kW	
CHP unit electrical efficiency	35.0%		
CHP natural gas fuel input	913	kW	
CHP natural gas input	3.11	MMBTU/hr	natural gas fuel required at full load
CHP natural gas input	3.11	MCF/hr	natural gas fuel required at full load
CHP thermal efficiency	45.0%		assumed thermal HW heat recovery efficiency
CHP thermal output	1.40	MMBTU/hr	hot water output for use in absorption chillers and heating coils.
typical single effect absorption chiller	0.70	COP	coeficient of performance of thermally activated chiller
max possible absorption chiller capacity	0.98	MMBTU/hr	
max possible absorption chiller capacity	82	tons	max chiller tonnage that the CHP free waste heat can provide
Lighting + Dehumidification Loads to Size Absorption Chiller			
Sensible heating from lighting	320	kW	all electrical energy from lights must be removed by cooling
Sensible heating from lighting	1,090,134	BTU / hr	
Avg. irrigation rate	750.6	lb / hr water	average rate of water evaporation from plants
Latent heat of evaporation	970	BTU / lb	unt conversion of one pound of water into BTU's of cooling
Evaporative cooling from water	728,082	BTU / hr	total evaporative cooling effect from plants
Net sensible heating (lights - evap.)	362,052	BTU / hr	net cooling required
Net sensible heating (lights - evap.)	30	tons	one ton of cooling = 12,000 BTU / hour (melt a ton of ice / day)
Dehumidification chilled water load	728,082	BTU / hr	from above evaporative cooling. All water must be condensed
Dehumidification chilled water load	61	tons	
Total chilled water load	**91**	**tons**	
Number of chillers sized to meet load	2		
Chiller size each (absorption)	45	tons	
Extra redundant unit (+1)	45	tons	
Total Numbe of Chillers	3		
Chiller size each (absorption)	45	tons	
Total absorption chiller plant capacity	**136**	**tons**	
Boiler Sizing			
Backup boiler (sized to run one absorber)	778,667	BTU / hr	currently, boiler is sized for one absorber (need to discuss)
	0.78	MMBTU/hr	
	0.78	MCF/hr	
Redundancy boiler for absorbers	1.56	MMBTU/hr	
Est approx. boiler size	1.00	MCF/hr	

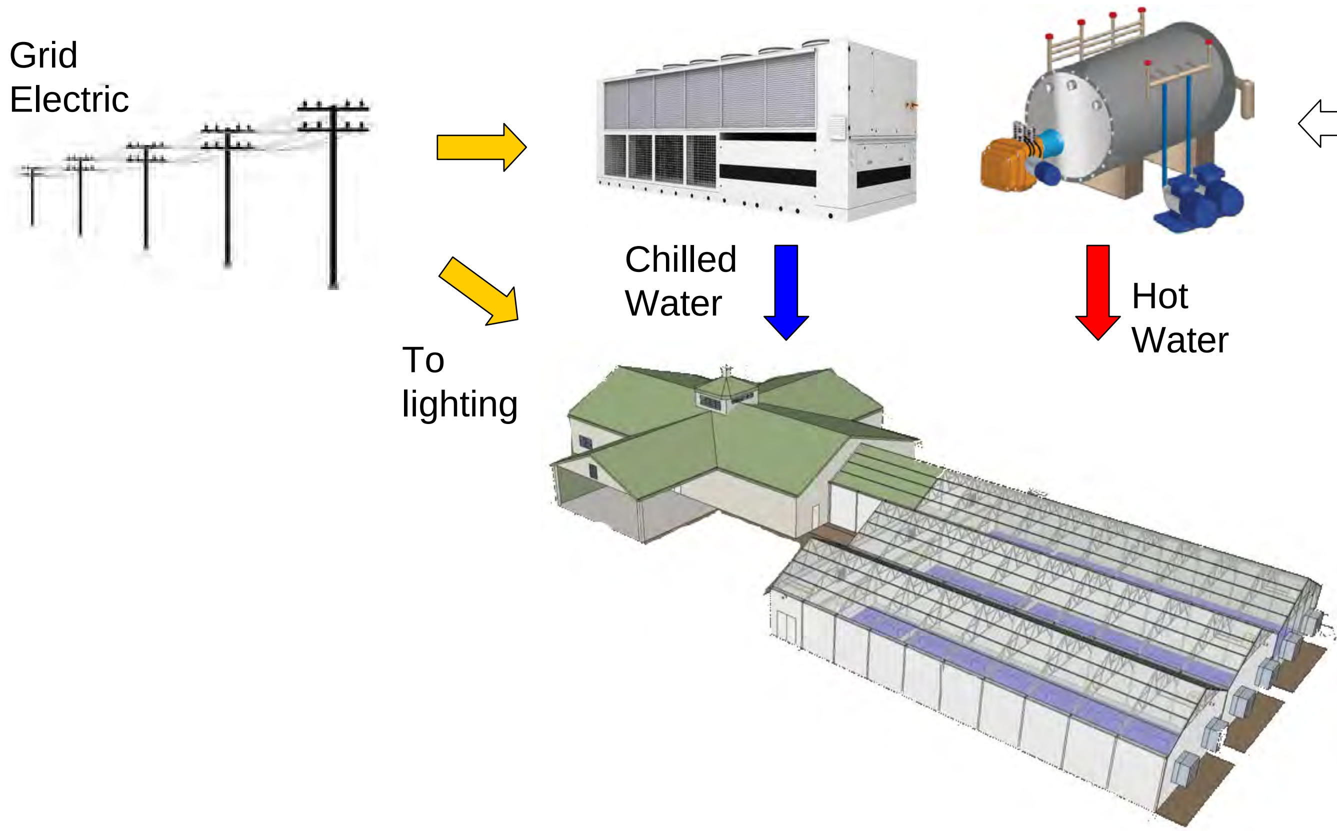
Combined Heat and Power



combined efficiency is dramatically increased

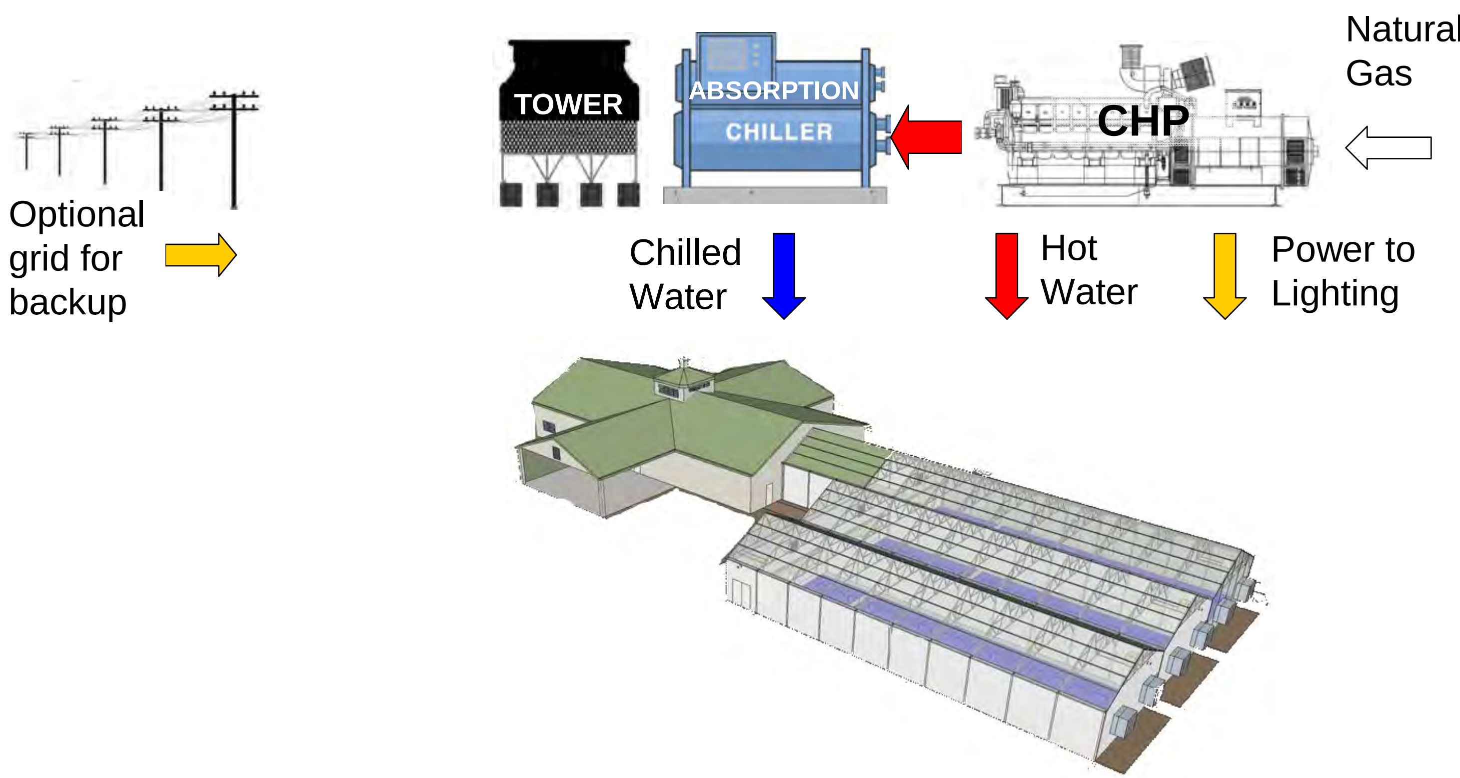
Conventional electric grid solution

- utility electric for lighting
- utility electric air cooled chiller cooling & dehumidification
- natural gas hot water boiler heating



Full natural gas solution with CHP

- utility electric for backup only
- natural gas Combined Heat and Power (CHP)
- waste heat absorption chiller (for cooling & dehumidification)
- waste heat, hot water heating



Operating Energy Cost Comparisons

A: HPS on Grid with Electric A/C SEER=12
B: HPS on CHP (35% electrical efficiency & absorption clg COP=0.7)
C: LED on CHP (35% electrical efficiency & absorption clg COP=0.7)

Grid Electric:	$0.12	per kWh
	$120.00	per MWh
Natural Gas:	$5.00	per MMBTU

	Total Veg & Grow Fixture	Total Fixture	Ballanced Lighting +20%	Cooling	Lighting Energy	Ballanced Lighting +20%	Cooling	CHP + Boiler Gas	Total Electric	Total Natural Gas	**Total Energy Cost**
	count	kW	kW	tons	MWh/yr	MWh/yr	MWh/yr	MMBTU/yr	dollars/yr	dollars/yr	dollars/yr
HPS on Grid	300										
HPS on CHP	300										
LED on CHP	300										

Operating Energy Cost Comparisons

A: HPS on Grid with Electric A/C SEER=12
B: HPS on CHP (35% electrical efficiency & absorption clg COP=0.7)
C: LED on CHP (35% electrical efficiency & absorption clg COP=0.7)

Grid Electric:	$0.12	per kWh
	$120.00	per MWh
Natural Gas:	$5.00	per MMBTU

	Total Veg & Grow Fixture	Total Fixture	Ballanced Lighting +20%	Cooling	Lighting Energy	Ballanced Lighting +20%	Cooling	CHP + Boiler Gas	Total Electric	Total Natural Gas	**Total Energy Cost**
	count	kW	kW	tons	MWh/yr	MWh/yr	MWh/yr	MMBTU/yr	dollars/yr	dollars/yr	dollars/yr
HPS on Grid	300	315	320	91							
HPS on CHP	300	315	320	91							
LED on CHP	300	180	186	53							

Operating Energy Cost Comparisons

A: HPS on Grid with Electric A/C SEER=12
B: HPS on CHP (35% electrical efficiency & absorption clg COP=0.7)
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HPS on Grid	300	315	320	91	2,016	2,799	801				
HPS on CHP	300	315	320	91	2,016	2,799	0				
LED on CHP	300	180	186	53	1,177	1,629	0				

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Operating Energy Cost Comparisons

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Savings between A and C =
$594,000 per year

Grid Electric:	$0.12	per kWh
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Natural Gas:	$5.00	per MMBTU

	Total Veg & Grow Fixture	Total Fixture	Ballanced Lighting +20%	Cooling	Lighting Energy	Ballanced Lighting +20%	Cooling	CHP + Boiler Gas	Total Electric	Total Natural Gas	**Total Energy Cost**
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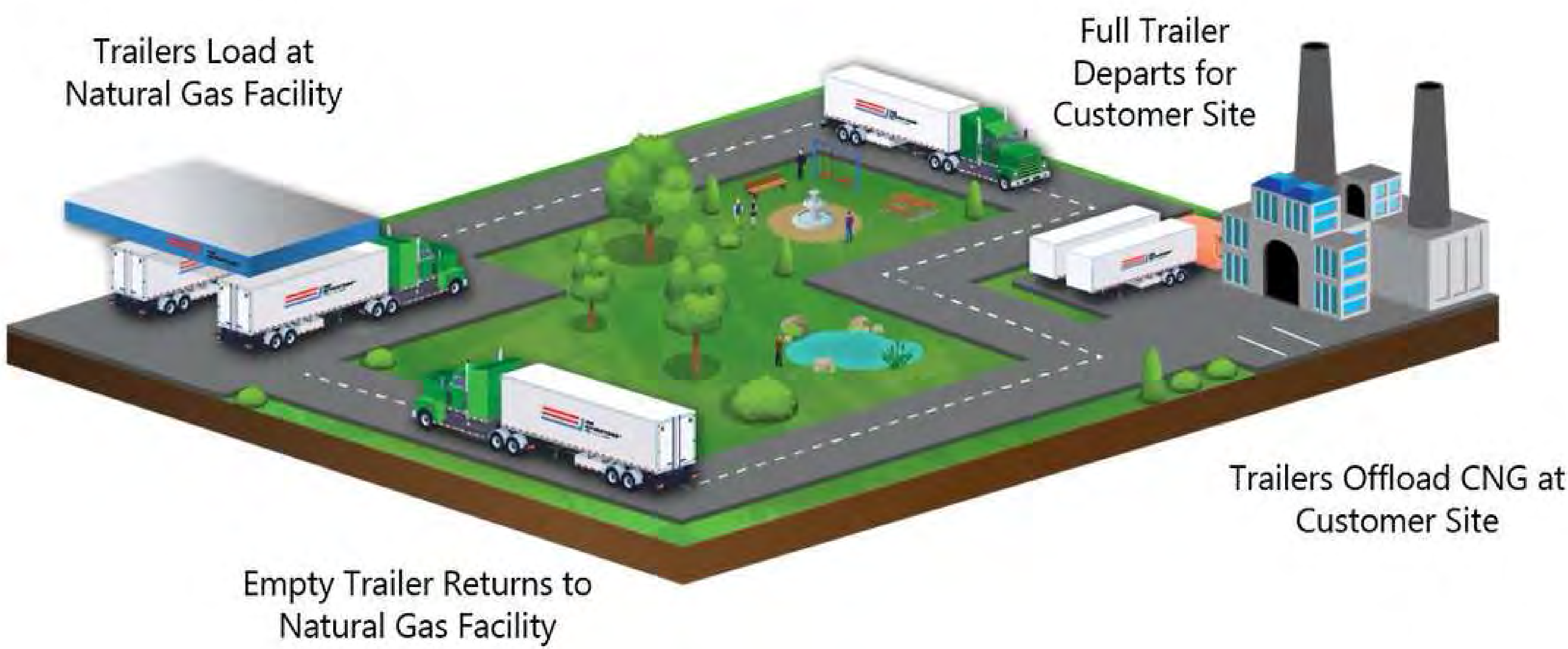
LED on CHP	300	180	186	53	1,177	1,629	0	15,900	$0	$79,500	**$79,500**

Now include maintenance contracts and cost of capital to calculate a return on your CHP plant investment.

Project Development Notes for Discussion

- Construction timeline and phasing?
- Perform electric rate analysis with various lighting schedules
  - Compare to CHP, on site power generation
- Availability and capacity of sufficient 3 phase power
  - Cost to upgrade service to required capacity
- Availability, capacity and pressure of local natural gas supply
  - Cost to upgrade to required capacity
- Electric chilling vs CHP/absorption chilling cost comparison
- Look at all options, perform a 5-10 year pro-forma on various solutions to select optimal system.

Virtual Pipeline Option to Start (CNG)



Conclusions

- LED tech is maturing and will be the most efficient and effective growing option for artificial light,
- Fully indoor grow environments have different load profiles and energy use requirements: cooling & dehumidification dominate,
- Supplying sufficient energy to serve your facility and operations can be done more cost effectively with Natural Gas,
- Low cost natural gas CHP can substantially lower your operating costs.

Questions ?

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